AD 634503

AD

USAAVLABS TECHNICAL REPORT 66-47

CH-54A SKYCRANE ENGINE LOAD SHARING

Engineering Laboratory Report

By

David Chestnutt

L. R. Bartek

DDC
RECEIVED
JUL 1 1966
B

May 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

CLEARINGHOUSE
FOR FEDERAL SCIENTIFIC AND
TECHNICAL INFORMATION

Hardcopy	Microfiche		
$3.00	$ .50	54 pp	

ARCHIVE COPY

U. S. ARMY MATERIEL COMMAND

Distribution of this document is unlimited

Project 1M121401D14415, House Task EL 65-29
USAAVLABS Technical Report 66-47
May 1966

CH-54A SKYCRANE
ENGINE LOAD SHARING

Engineering Laboratory Report

By

David Chestnutt
L. R. Bartek

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

Distribution of this
document is unlimited

SUMMARY

The Army is considering the use of multiengine heavy-lift helicopters in its future aviation program. The engine load-sharing characteristics of the CH-54A Skycrane helicopter were investigated to determine if unequal load sharing would be a significant problem. Torque-split samples were selected from 67 hours of flight-load data. The parameters measured and recorded on oscillograph records were airspeed, altitude, engine gas producer rpm, engine torque, main rotor rpm, vertical acceleration at aircraft center of gravity, and outside air temperature. The gross weight at takeoff and landing and the barometric pressure were measured and recorded as supplemental data. The data were presented in a series of frequency-of-occurrence graphs; variation in torque splits was indicated with the other measured parameters. The analysis of the data indicates that the engine load splitting is significant at takeoff and landing and should be investigated further.

FOREWORD

This program was sponsored by the Propulsion Division of the U. S. Army Aviation Materiel Laboratories (USAAVLABS), and the work was performed by the Engineering Laboratories Division.

Acknowledgment is given to Technology Incorporated for assistance in data acquisition and, in particular, to Messrs. Joseph Braun and David Etter for their contribution to this report.

BLANK PAGE

CONTENTS

ILLUSTRATIONS

Figure		Page

BLANK PAGE

INTRODUCTION

The development of a helicopter having more than two engines is currently of interest to the U. S. Army. In order to design such an aircraft, it is necessary to know how several helicopter engines behave if they share the same load.

The CH-54A Skycrane has two engines, and its primary mission function of carrying heavy loads corresponds to that of the proposed multiengine, heavy-lift helicopter. Because of these two characteristics, the Skycrane helicopter was the aircraft selected for this study on engine load sharing.

Four helicopters were used as data sources for this report. Tests were conducted under a variety of flying conditions.

An oscillograph recorder system was used to record data on the following parameters: airspeed, altitude, main rotor rpm, engine gas producer rpm, engine torque, and outside air temperature; also, vertical acceleration at the aircraft's center of gravity, barometric pressure, and aircraft gross weight were measured as supplemental data.

The data were scanned to find areas where the torque split between the two engines was significant. All of the other parameters were tabulated at this time, and an attempt was made to correlate torque split with the variation in the other parameters.

OBJECTIVES

Following are the objectives of this study:

1. To determine if an appreciable torque split occurs on multiengine helicopters and, if so, the magnitude of these splits.

2. To determine which flying conditions produce the highest frequency of torque splits.

3. To make recommendations as to what future tests should be conducted to establish reliable design criteria for multiengine helicopters.

PROCEDURES

INSTRUMENTATION

The engine parameters, torque and gas producer rpm, were obtained by tapping the aircraft systems, and special circuitry was added before the signals were fed into the oscillograph recorder (see Figures 1 and 2, pages 18 and 19). The other parameters were obtained as follows: the airspeed, by tapping the aircraft pitot system and by attaching a differential pressure strain-gage-type transducer; the altitude, by tapping the aircraft static pressure system and by attaching an absolute pressure strain-gage transducer; the outside air temperature (OAT), by gluing a resistance-type ribbon thermometer to the underside of the aircraft; the two stick positions, by attaching potentiometers to the sticks; the main rotor rpm, by tapping the output of the aircraft tachometer generator and by adding special circuitry; the vertical acceleration at the aircraft center of gravity, by mounting a strain-gage-type accelerometer at a position on the side of the main cargo-hook well. In addition to the flight parameters, the oscillograph made a record of aircraft voltage and chart speed (see Figure 3, page 20).

DATA REDUCTION

Sample Selection

In order to investigate the engine load-sharing characteristics of the CH-54A Skycrane helicopter, sample data points were selected from among 67 hours 6 minutes of flight-load oscillograph records.

Areas to be analyzed were found by scanning each record in search of sections in which significant splits had occurred between the gas producer rpm for each engine and the torque for each engine. Indications of unbalanced load sharing were found in cruising, hover, takeoff, and landing sections of records, but most frequently the unequal load sharing occurred during takeoff and landing segments.

The torque-split data were selected on the basis of extreme conditions. If a record contained one torque split of 20 percent and another of 40 percent, only the data indicating the greater imbalance of load sharing were to be calculated.

This load-sharing report is not meant to be a time history; however, the sum of the time included in torque-split samples is 140.8 minutes. This time represents 3.5 percent of the 67 hours 6 minutes from which data were selected.

The data samples that were calculated usually consisted of one point preceding and one following the unbalanced load-sharing section of data. The preceding and following points were selected at a time when a steady-state load-sharing condition was in effect. From one to five data points were taken during the active load-sharing condition, depending upon how much variation was experienced. Maximum torque splits or sharply changing torque traces determined when the calculations were to be made.

During several landing samples, it was impossible to calculate a following point in the steady-state condition because the recorder was cut off soon after landing without allowing a steady condition to be reestablished.

The data samples taken at each point include a time, in minutes, from the beginning of the flight and a gross weight for that time based on a known takeoff gross weight and fuel consumption rate. Outside air temperature and pressure altitude channels were monitored, and from this information, density altitudes were calculated. The main rotor rpm, the torques from each engine, and the gas producer rpm for each engine were also calculated for each sample point.

Data Processing

After the data samples were selected for analysis, the individual points were calculated for tabulation. The oscillograph record contained a reference trace, and measurements were made to determine how much deflection existed between each active channel and the reference. This deflection was compared with the amount of deflection existing at a zero point or known magnitude point for each channel. A calibration factor was applied to the difference between deflections of a known magnitude point and a data sample point to calculate the physical magnitude of the quantity being measured. This method of calculation was used for everything except gross weight and time.

The oscillograph chart speed was set at 4 inches per minute, but the actual rate was slightly slower or faster. To obtain a time calibration, the technician turned the voltage off for a known time while the recorder chart was running. The ratio of the length of chart run in a known time to the distance it should have run at the rate of 4 inches per minute yielded a multiplying factor with which to calculate the correct chart speed. This was calculated to the nearest .1 minute. When a record was edited for processing, a template was used which marked time panels as if the 4-inch-per-minute chart speed were always in effect. Later, when the data were calculated and analyzed, the time correction factor was applied. The gross weights were calculated by using a supplemental data sheet, which accompanied each record. The takeoff gross weight and the fuel consumption rate were listed by the technician in the field. To calculate the gross weight at any known time, the fuel consumption rate was multiplied by the time from takeoff, and this weight was subtracted from the gross takeoff weight. Any cargo pickups or drops were added to or subtracted from the weight calculated on the basis of fuel consumption.

To illustrate, sample calculation 30, point 1, flight A35 follows:

TIME

Time panel, 55.0 minutes
Volts off, 60 seconds
Length of deflected voltage trace, 3.85 inches
Theoretical length of trace, 4.00 inches

$$\text{Time correction factor} = \frac{4.00 \text{ inches}}{3.85 \text{ inches}} = 1.039 \text{ inches}$$

True time = (time panel) (time correction factor)
True time = (55.0) (1.039) = 57.15
True time to nearest .1 minute = 57.1 minutes

GROSS WEIGHT

The takeoff gross weight was listed as 32,830 pounds; the fuel consumption rate, as 56.0 pounds per minute. The amount of fuel used in 57.1 minutes, at 56.0 pounds per minute, was 3,198 pounds. Since no loads were picked up or dropped, the gross weight at 57.1 minutes was 29,632 pounds (32,830 - 3,198).

TORQUE

To calculate the torque on each engine, the deflection of each torque trace from the reference was measured with zero torque applied. In this case, the deflection was 1.88 inches for torque 1 and 1.81 inches for torque 2. At 57.1 minutes, the deflections of torques 1 and 2 from the reference were 1.59 inches and 1.67 inches, respectively.

The difference in deflections from the zero loading condition was proportional to the torque applied on each engine. The slopes on the torque measuring instruments for engines 1 and 2 were, respectively, 1.250 percent per .01-inch deflection and 1.316 percent per .01-inch deflection. From this information, the following calculations were made:

Torque 1: (1.88 in. - 1.59 in.) (1.250 pct/.01 in.) = 36.3 pct

Torque 2: (1.86 in. - 1.67 in.) (1.316 pct/.01 in.) = 25.0 pct

Torque split: 36.3 pct - 25.0 pct = 11.3 pct

GAS PRODUCER RPM

For each engine, the gas producer rpm (ΔN_I) was calculated similarly to the torque.

MAIN ROTOR RPM

The main rotor rpm (ΔN_{II}) was calculated in much the same manner as were the torque and the gas producer rpm.

AIRSPEED

The method of calculating airspeed varied slightly from that used in calculating the preceding parameters. A differential pressure measuring instrument was used in conjunction with a table of differential pressures and airspeeds to calculate airspeed. At 57.1 minutes, the airspeed trace was .65 inch from the reference. The calibration factor for the pressure measuring instrument in use was .925 inch of mercury. The calibration pulse with a known resistance in the circuit was a .74-inch deflection; therefore, the calibration constant was .925 inch of mercury per .74-inch deflection. Following are the steps used to calculate a pressure difference due to airspeed:

Pressure differential = (.65 in. - .28 in.) (.925 in. Hg/ .74 in. deflection) = .46 in. Hg

From a table of differential pressures in inches of mercury and velocities in knots, interpolation will yield the airspeed in knots, as follows:

0.46 in. Hg = 97.6 knots

Figure 3 (see page 20) shows a reproduction of the segment of an oscillograph record from which sample 30 was calculated.

RESULTS

The 59 samples included 219 data points (see Table I). Figures have been generated to show frequency of occurrence by ranges of torque split, airspeed, gross weight, gas producer rpm split, and main rotor rpm. Average torque versus frequency of occurrence was also plotted over a series of torque-split ranges. The average torque was found by adding the torques of each engine and then dividing by two. These histograms are shown as Figures 4 through 49 (see pages 21 through 42).

The plot of frequency of occurrence versus ranges of torque splits indicates that nearly half of the torque-split sample points are in the 0- to 10-percent-torque-split range. This distribution occurred because of the manner in which sample points were selected. The relatively steady preceding and following points for each sample had only slight torque splitting. For greater torque splits, the frequency of occurrence was inversely proportional to the magnitude of the torque split.

A close correlation is indicated between the graph showing a variation in gas producer rpm versus frequency of occurrence and the graph showing a variation in torque split versus frequency of occurrence. The gas producer rpm splits are the least where the frequency is the greatest, just as the torque splits are the least where the frequencies are the highest.

The curve showing main rotor rpm versus frequency of occurrence indicates that nearly three-fourths of the sample points are in the 184.1- to 194.0-rpm range. Since the 100-percent rpm condition for the CH-54A is 185 rpm, this distribution is to be expected.

Nearly three-fourths of the sample points arranged by ranges of gross weights fell into the 24,000- to 32,000-pound category. Since the gross weight of the Skycrane with a full load of fuel and with a complete crew is approximately 29,000 pounds, the sample distribution is not unexpected. Because so many points were selected under takeoff or landing conditions, nearly half of the sample points were included in the airspeed range of 0 to 10.0 knots. Over one-fourth of the points were between 80 and 110 knots, which is the normal operating speed range of the aircraft.

The distribution of ranges shown on the graphs for average torque versus frequency of occurrence places nearly three-fourths of the data points at from 20-percent to 40-percent average torque.

All of the above-mentioned plots have been broken down further by ranges of torque splits, and inspection of the figures will show trends that occurred.

TABLE I

INVESTIGATION OF HEAVY-LIFT HELICOPTER ENGINE LOAD SHARING

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Air-speed (kn)	Density Alt (ft)	Outside Air Temp (°F)
1	205	A11	0.0	29,000	0.0	24.6	11,092	13,333	189.9	0.0	143	61
1	205	A11	0.2	29,000	27.6	55.1	13,976	14,912	193.1	0.0	-12	60
1	205	A11	1.0	29,000	50.8	40.6	14,253	14,386	189.9	82.0	717	52
2	205	A11	18.6	27,200	1.5	23.2	10,981	13,099	189.9	0.0	-183	49
2	205	A11	18.7	27,200	17.4	47.8	13,033	14,854	188.1	0.0	401	59
2	205	A11	18.7	27,200	53.6	29.0	14,863	13,801	189.9	0.0	436	59
2	205	A11	19.3	27,200	59.4	43.5	14,808	14,737	189.9	91.0	651	60
3	205	A12	0.0	28,800	27.6	0.0	13,699	10,926	188.1	0.0	941	73
3	205	A12	0.7	28,800	2.9	34.8	11,147	13,743	189.3	0.0	832	72
3	205	A12	0.9	28,800	66.7	14.5	15,695	12,807	192.4	0.0	809	72
3	205	A12	1.4	28,900	43.5	37.7	14,253	14,503	193.1	34.1	859	71
4	205	A12	77.1	25,700	26.1	24.6	13,089	13,743	191.8	86.8	1447	68
4	205	A12	77.7	25,700	4.4	26.1	11,092	13,099	191.2	53.8	966	70
4	205	A12	78.1	25,700	0.0	46.4	5,546	15,088	203.1	11.6	708	69
4	205	A12	79.0	25,700	18.8	30.4	12,922	13,918	191.8	17.6	689	68
5	202	A13	0.0	24,600	39.6	4.1	13,834	11,536	181.1	0.0	-288	55
5	202	A13	0.6	24,600	50.5	12.4	14,483	12,528	188.7	0.0	-265	55
5	202	A13	0.2	24,600	13.6	39.9	11,997	15,086	191.3	12.1	-109	57
5	202	A13	1.0	24,600	34.1	39.9	13,942	14,564	190.5	91.1	747	62
6	202	A13	9.5	24,400	30.0	31.7	13,294	14,146	191.8	0.0	10	55
6	202	A13	9.9	41,600	57.3	59.2	15,293	16,286	181.1	0.0	33	55
6	202	A13	10.5	41,600	50.5	59.2	14,591	15,817	189.9	24.5	189	57
7	203	A56	4.2	38,300	37.5	30.3	14,678	14,633	190.3	91.0	1882	73
7	203	A56	4.5	38,300	75.0	0.0	16,885	9,455	195.7	88.2	1916	73
7	203	A56	5.2	38,300	91.2	0.0	17,061	9,568	174.1	96.0	2021	73
7	203	A56	5.8	38,300	37.5	40.8	14,512	15,477	186.9	92.2	1963	73
7	203	A56	7.2	38,300	0.0	81.6	9,767	17,390	174.1	64.0	1905	73
7	203	A56	8.0	38,300	37.5	40.8	14,678	15,252	184.9	86.2	2033	73
7	203	A56	8.6	38,300	31.2	35.5	14,402	14,745	191.7	94.1	2371	73
8	202	A14	1.4	42,600	32.7	31.7	15,510	14,564	190.5	0.0	126	51
8	202	A14	2.0	42,600	68.2	71.6	15,564	16,652	186.1	0.0	-9	49
8	202	A14	2.5	42,600	68.2	64.8	15,672	16,756	186.1	0.0	26	49

TABLE I - contd.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (^{o}F)
9	202	A16	17.6	41,700	23.2	26.2	13,456	13,781	194.9	49.6	1457	64
9	202	A16	18.1	41,700	51.8	66.1	15,618	16,339	189.9	4.1	1223	62
9	202	A16	18.5	41,700	21.8	30.3	13,618	14,564	192.4	0.0	1076	61
9	202	A16	18.8	41,700	31.4	38.6	14,375	14,929	193.7	59.4	257	61
10	203	A62	62.9	31,100	30.0	27.6	14,236	14,183	193.0	76.8	3770	88
10	203	A62	63.8	31,100	12.5	22.4	13,188	13,507	193.0	45.5	3441	88
10	203	A62	64.3	31,100	15.0	27.1	13,354	13,170	193.7	15.7	3124	87
10	203	A62	64.9	31,100	32.5	35.5	14,347	14,858	192.3	0.0	2696	84
11	203	A63	87.5	28,700	30.0	34.2	14,623	14,183	191.7	90.0	2782	79
11	203	A63	88.4	28,700	6.3	11.8	11,698	12,494	190.3	50.0	1994	79
11	203	A63	89.2	28,700	32.0	30.3	14,347	14,408	192.3	0.0	1775	81
12	203	A55	2.6	38,500	40.0	35.5	14,678	14,633	188.[illegible]	80.4	1259	64
12	203	A55	2.8	38,400	82.0	1.3	17,051	8,217	184.0	82.5	1259	62
12	203	A55	4.1	38,400	31.2	46.1	14,457	15,139	193.4	56.0	368	64
12	203	A55	4.9	38,300	41.2	38.2	14,843	15,027	191.0	71.0	778	63
13	203	A55	18.2	37,600	40.0	34.2	14,843	14,745	188.3	95.8	1773	66
13	203	A55	18.4	37,600	0.0	65.8	10,043	16,940	200.5	90.6	1820	66
14	204	A80	3.8	29,600	33.8	39.5	15,009	14,802	196.5	7.9	2579	95
14	204	A80	3.9	29,600	1.3	72.4	10,263	17,165	193.2	0.0	2541	94
15	204	A80	12.5	29,200	55.0	30.3	16,278	14,183	195.2	111.7	1862	78
15	204	A80	12.7	29,200	12.5	56.6	12,581	16,265	191.1	108.0	1874	78
15	204	A80	12.9	29,100	40.0	36.8	15,340	14,520	193.2	108.6	1862	78
16	204	A80	89.8	25,300	33.8	29.0	14,678	14,014	197.2	86.3	3533	87
16	204	A80	90.4	25,300	78.8	6.6	17,823	10,187	184.4	72.2	3644	84
16	204	A80	90.9	25,300	41.2	40.8	14,788	15,139	189.1	81.8	4188	81
16	204	A80	92.7	25,200	2.5	81.6	9,712	17,784	181.0	77.3	4342	78
16	204	A80	94.2	25,100	7.5	17.1	12,691	13,282	205.3	83.3	3672	75
16	204	A80	95.1	25,100	76.2	5.3	17,768	10,412	181.0	62.9	3799	78
16	204	A80	95.9	25,000	13.8	18.4	12,526	13,789	204.6	73.5	3476	78
16	204	A80	97.1	25,000	25.0	27.6	14,236	13,901	194.5	87.0	2809	83

TABLE I - contd.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (°F)
17	202	B07	10.0	25,300	34.8	40.6	14,586	15,380	187.8	78.2	3027	93
17	202	B07	10.5	25,300	39.2	29.0	14,586	14,445	187.1	86.2	3269	89
17	202	B07	10.7	25,200	21.8	39.2	13,532	14,620	188.4	91.7	3269	89
17	202	B07	10.9	25,200	56.6	14.5	15,640	10,292	185.9	86.8	3124	87
18	202	B07	15.4	24,900	37.7	43.5	14,697	15,731	189.7	68.2	3286	91
18	202	B07	16.0	24,900	27.6	29.0	13,865	14,737	189.7	95.5	3298	87
18	202	B07	16.5	24,800	42.0	1.4	14,863	10,526	186.5	88.2	3217	87
19	202	B07	19.2	24,600	47.8	7.2	15,362	12,866	189.0	0.0	2458	96
19	202	B07	19.4	24,600	31.9	33.4	14,253	15,380	190.3	0.0	2481	96
19	202	B07	19.8	24,600	49.3	33.4	14,974	15,205	191.5	50.1	2767	97
19	202	B07	20.6	24,500	33.4	45.0	13,920	15,848	189.7	84.8	3353	90
19	202	B07	23.7	24,300	7.2	59.4	10,371	17,076	194.1	0.0	2371	94
20	202	B07	46.2	22,600	21.8	27.6	12,867	14,386	186.5	89.0	3404	87
20	202	B07	46.4	22,600	10.2	16.0	10,704	10,409	171.4	61.2	2892	87
20	202	B07	46.9	22,600	42.0	4.4	14,531	12,573	193.4	7.2	2548	93
20	202	B07	47.3	22,500	14.5	58.0	11,868	16,491	179.6	0.0	2662	96
20	202	B07	47.6	22,500	66.7	2.9	15,862	12,047	193.4	0.0	2865	99
20	202	B07	48.1	22,500	33.4	33.4	13,920	15,380	197.2	0.0	2820	99
21	202	B07	62.4	21,400	40.6	29.0	14,142	14,328	187.1	79.2	3970	88
21	202	B07	62.9	21,400	29.0	36.2	13,421	14,971	185.3	74.4	4146	86
21	202	B07	63.5	21,300	36.2	26.1	13,976	14,211	186.5	67.1	4227	84
21	202	B07	63.8	21,300	27.6	33.4	13,421	14,912	187.8	57.0	4213	82
22	202	B08	65.9	24,800	26.1	27.6	13,255	14,152	188.4	84.4	2550	82
22	202	B08	67.2	24,700	10.2	65.2	10,038	1[illegible],018	188.4	7.2	2159	87
22	202	B08	68.1	24,700	36.2	39.2	14,087	15,556	190.9	0.0	2343	90
23	202	B01	93.8	24,400	29.0	24.6	14,198	14,620	188.7	0.0	2926	90
23	202	B01	94.0	24,400	63.8	4.4	16,028	8,012	182.4	0.0	3070	92
23	202	B01	94.9	24,300	23.2	33.4	13,810	15,322	191.2	0.0	3131	93
23	202	B01	95.3	24,300	40.6	20.3	14,976	14,269	189.3	1.9	3214	94
23	202	B01	95.9	24,300	30.4	34.8	14,364	14,912	189.3	79.2	3500	88

TABLE I - contd.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (^{o}F)
24	202	B03	9.1	25,400	20.3	33.4	13,865	14,912	188.7	90.3	4212	81
24	202	B03	9.3	25,400	1.4	46.4	11,480	15,848	184.9	100.0	4248	81
24	202	B03	9.5	25,300	26.1	27.6	13,920	14,386	183.0	101.0	4092	81
24	202	B03	9.6	25,300	36.2	14.5	14,640	13,100	183.0	97.7	3984	81
24	202	B03	9.9	25,300	21.8	30.4	13,865	14,854	185.6	94.2	3876	81
25	203	A33	0.0	29,200	1.2	51.3	11,864	15,364	189.7	0.0	1004	69
25	203	A33	0.3	29,200	52.5	22.4	15,395	13,451	190.4	10.7	1363	73
25	203	A33	0.7	29,200	47.5	48.7	14,843	15,590	189.7	73.9	2007	77
26	203	A35	-1.6	32,800	20.0	78.9	13,188	12,156	192.4	0.0	-540	49
26	203	A35	-1.3	32,800	25.0	5.2	13,574	11,312	193.0	0.0	-473	50
26	203	A35	0.0	32,800	23.7	56.6	13,243	15,589	189.7	0.0	-575	49
26	203	A35	1.3	32,800	47.5	39.5	14,788	14,576	191.0	65.8	-516	48
27	203	A33	7.5	28,700	30.0	39.5	14,788	14,577	191.7	0.0	1299	72
27	203	A33	7.9	28,700	21.2	46.1	13,409	15,646	193.7	0.0	1363	73
27	203	A33	8.5	28,700	37.5	29.0	14,512	14,577	191.0	0.0	1426	74
28	203	A33	42.5	26,400	31.2	31.6	14,181	14,577	193.0	0.0	1363	73
28	203	A33	43.0	26,300	66.2	2.6	16,609	5,403	201.8	0.0	1490	75
28	203	A33	43.6	26,300	33.8	34.2	14,457	14,689	195.8	0.0	1541	76
28	203	A33	43.8	26,300	16.2	50.0	12,967	15,815	196.4	0.0	1541	76
28	203	A33	44.5	26,200	33.8	34.2	14,899	14,070	195.1	0.0	1490	75
29	203	A33	58.4	25,300	32.5	25.0	13,961	14,014	195.1	92.5	1985	66
29	203	A33	58.9	25,300	51.2	3.9	15,230	8,104	199.8	86.4	2032	66
30	203	A35	57.1	29,600	36.2	25.0	13,739	13,732	193.7	97.6	-8	52
30	203	A35	57.7	29,700	30.0	5.3	13,353	10,805	193.7	76.9	429	51
30	203	A35	58.6	29,500	45.0	34.2	14,402	14,070	193.7	0.0	103	55
31	203	A33	60.3	25,200	1.2	31.6	11,257	14,970	193.7	0.0	1265	72
31	203	A33	60.3	25,200	33.8	22.4	14,236	14,014	199.1	0.0	1265	72
31	203	A33	60.4	25,200	56.2	0.0	16,113	11,087	199.1	0.0	1392	74
31	203	A33	60.7	25,100	33.8	26.3	14,457	14,408	201.8	0.0	1519	76
31	203	A33	61.2	25,100	25.0	35.5	14,016	14,970	196.4	0.0	1519	76
32	203	A35	104.5	26,800	32.5	23.7	13,684	13,394	195.0	87.4	1485	59
32	203	A35	105.1	26,700	22.5	18.4	13,133	11,087	193.7	62.0	1062	59
32	203	A35	106.0	26,700	40.0	32.9	14,512	14,023	196.4	0.0	739	64

TABLE I - contd.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (^{o}F)
33	203	A33	89.2	23,200	6.2	42.1	11,919	15,364	191.7	0.0	1753	77
33	203	A33	89.3	23,200	36.2	17.1	15,119	13,338	198.4	0.0	1788	77
33	203	A33	90.2	23,100	41.2	32.9	14,457	14,464	192.4	76.3	2828	69
34	203	A34	30.8	31,500	33.8	34.2	14,568	14,577	194.4	0.0	-219	55
34	203	A34	31.8	31,500	2.5	82.9	11,367	16,546	185.0	0.0	-262	54
34	203	A34	31.5	31,500	37.5	38.2	15,230	14,126	193.0	0.0	-240	54
34	203	A34	31.7	31,500	51.2	38.2	16,002	14,014	193.7	82.5	-291	51
34	203	A34	32.7	31,400	40.0	25.0	14,402	13,957	179.8	53.0	-8	49
35	202	A36	7.9	28,700	25.9	16.5	12,807	13,780	189.3	82.6	267	54
35	202	A36	8.7	28,600	12.3	30.3	10,483	14,929	186.8	62.0	97	53
35	202	A36	10.1	28,600	13.6	50.9	10,159	16,339	184.0	0.0	42	56
35	202	A36	11.6	28,500	31.3	0.0	13,077	10,909	191.0	0.0	131	57
36	203	A60	1.1	28,800	26.3	32.9	14,788	14,914	193.0	0.0	1542	78
36	203	A60	2.2	28,700	0.0	69.7	8,221	17,053	186.0	0.0	1542	78
36	203	A60	4.2	28,500	28.8	32.9	14,678	14,858	189.1	0.0	1645	78
37	203	A20	49.1	26,000	32.5	30.3	14,181	13,563	191.8	100.9	1255	42
37	203	A20	51.2	25,000	18.8	42.1	12,691	14,858	191.8	105.0	1371	43
37	203	A20	51.8	25,800	22.5	39.5	13,795	13,901	187.1	98.5	1462	42
37	203	A20	53.2	25,700	23.8	34.2	13,574	13,957	193.0	109.0	1468	41
38	203	A21	25.3	24,000	21.3	30.2	13,519	13,901	193.2	90.7	605	48
38	203	A21	26.8	23,900	16.3	35.5	12,691	14,464	193.2	94.3	463	48
38	203	A21	28.0	28,900	32.5	25.0	11,367	10,806	193.8	93.2	581	48
39	202	A10	.6	32,400	11.0	0.0	12,916	10,805	188.0	0.0	1560	85
39	202	A10	.2	32,400	8.2	28.6	12,429	15,555	191.8	0.0	1475	84
39	202	A10	.3	32,400	37.2	4.1	15,239	11,536	189.9	0.0	1475	84
39	202	A10	.9	32,400	19.1	19.3	13,618	14,303	193.0	3.1	1520	84
40	203	A31	53.1	26,200	35.0	26.3	13,961	13,507	193.7	91.8	846	47
40	203	A31	54.0	26,100	46.3	2.6	15,947	8,386	193.7	88.6	381	48
40	203	A31	55.8	26,000	38.8	25.0	14,236	13,563	197.1	6.3	-766	46
41	203	A31	21.2	28,000	32.5	38.2	14,347	14,126	186.7	0.0	568	52
41	203	A31	21.6	27,900	1.3	79.0	8,111	16,265	188.7	0.0	568	52
41	203	A31	21.9	27,900	33.8	35.5	14,292	13,395	188.1	0.0	522	52
41	203	A31	22.0	28,000	62.5	3.9	16,444	10,299	196.0	0.0	522	52
41	203	A31	33.0	27,300	36.3	36.8	13,850	14,070	190.7	0.0	-589	51

TABLE I - contd.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque		Gas Producer		Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (^{o}F)
					1 (pct)	2 (pct)	1 (rpm)	2 (rpm)				
42	205	A24	16.2	27,800	39.1	23.2	13,809	13,509	189.0	62.0	4120	94
42	205	A24	17.0	27,700	4.4	55.1	6,045	15,380	188.6	55.0	4319	93
42	205	A24	18.1	27,700	37.7	29.0	13,809	13,626	189.0	74.7	4878	93
43	203	A31	84.3	24,400	23.8	34.2	12,967	13,957	191.7	82.6	382	51
43	203	A31	85.1	24,400	43.8	10.5	15,064	10,693	193.7	88.6	228	48
43	203	A31	85.5	24,400	23.8	36.8	13,795	13,620	195.1	92.1	339	50
43	203	A31	86.0	24,300	27.5	30.3	13,464	13,845	193.1	76.9	471	49
44	205	A25	3.5	28,500	45.0	33.4	13,754	13,918	188.6	93.0	463	61
44	205	A25	4.7	28,400	60.9	13.1	14,808	12,105	182.9	98.7	1193	61
44	205	A25	7.4	28,100	42.1	21.8	13,532	13,626	188.6	83.8	1231	58
45	203	A31	95.4	23,800	32.5	38.2	14,347	14,126	193.7	0.0	-64	57
45	203	A31	95.8	23,800	0.0	65.8	6,511	15,477	203.2	0.0	68	59
45	203	A31	96.3	23,700	25.0	35.5	13,795	13,620	200.4	0.0	111	60
45	203	A31	97.3	23,700	30.0	30.3	13,961	13,620	189.0	0.0	-242	55
46	202	B09	23.1	40,500	42.1	52.2	15,085	15,907	189.8	82.6	3737	71
46	202	B09	23.7	40,400	68.2	0.0	16,250	10,351	190.5	83.2	3698	70
46	202	B09	24.8	40,400	33.4	39.2	14,531	15,322	190.5	85.0	3453	69
47	203	A49	8.6	25,500	36.3	19.7	14,347	13,732	193.8	80.2	3046	77
47	203	A49	12.1	25,400	33.8	5.3	14,457	11,763	192.5	9.4	2064	84
47	203	A49	12.5	25,300	37.5	26.3	14,568	14,014	194.5	0.0	2092	85
48	202	B09	33.3	39,800	56.6	55.1	15,806	16,491	188.6	0.0	2559	70
48	202	B09	33.9	39,700	71.1	5.8	16,583	11,871	192.5	63.7	2888	69
48	202	B09	34.5	39,700	30.5	56.6	14,863	16,374	194.9	74.6	3611	69
48	202	B09	34.6	39,700	74.0	0.0	17,193	10,877	187.3	74.6	3684	69
48	202	B09	36.1	39,600	27.6	23.2	13,920	14,620	189.2	72.6	3582	67
49	203	A54	9.7	28,500	31.3	27.6	13,795	14,126	190.0	91.0	1186	60
49	203	A54	12.7	28,300	6.3	25.0	11,533	13,901	189.8	29.2	556	64
49	203	A54	13.2	28,300	36.3	36.8	14,512	14,914	191.0	0.0	666	68
50	203	A54	17.7	28,000	40.0	40.8	14,678	14,745	191.0	0.0	506	65
50	203	A54	18.3	28,000	85.0	1.3	17,051	7,935	180.0	22.0	860	68
50	203	A54	21.5	27,800	27.5	30.3	13,795	14,070	192.0	72.6	962	63

TABLE I - condt.

Sample No.	Acft No.	Flt No.	Time (min)	Gross Wt (lb)	Torque 1 (pct)	Torque 2 (pct)	Gas Producer 1 (rpm)	Gas Producer 2 (rpm)	Main Rotor (rpm)	Airspeed (kn)	Density Alt (ft)	Outside Air Temp (^oF)
51	202	B11	21.0	25,200	30.5	42.1	14,586	15,263	189.2	112.0	3696	75
51	202	B11	21.4	25,200	52.2	1.5	15,584	10,584	184.2	99.8	3634	74
51	202	B11	22.0	25,100	20.3	17.4	13,588	13,743	190.5	79.0	2298	75
51	202	B11	23.8	25,000	23.2	30.5	12,257	16,550	188.0	0.0	3286	78
51	202	B11	24.4	25,000	26.1	33.4	14,142	15,322	193.6	0.0	3312	79
52	203	A57	50.2	26,800	53.8	47.4	15,671	15,702	190.0	0.0	1204	75
52	203	A57	56.7	26,500	82.5	2.6	16,995	10,243	199.0	0.0	1009	73
52	203	A57	60.3	26,400	42.1	46.0	15,781	14,914	195.2	0.0	3418	74
53	202	B12	14.0	38,100	33.4	42.1	14,475	15,263	188.0	94.3	4217	75
53	202	B12	14.5	38,100	65.3	1.5	16,083	10,409	182.9	91.0	4180	74
53	202	B12	17.0	37,900	27.6	37.1	14,309	15,263	186.7	82.6	4374	73
54	202	B12	59.8	35,000	23.2	27.6	13,976	14,678	188.0	49.9	4121	76
54	202	B12	60.3	35,000	69.6	0.0	16,416	8,714	188.0	47.2	4063	78
54	202	B12	61.3	35,900	20.3	27.6	13,865	14,678	187.3	42.0	3953	77
55	203	A57	72.8	25,800	31.3	32.9	14,071	14,126	191.8	0.0	923	72
55	203	A57	73.4	25,700	57.5	1.3	15,937	6,134	200.0	0.0	998	73
56	202	B13	47.8	26,500	23.2	16.0	13,477	13,392	188.0	81.4	4489	79
56	202	B13	49.4	26,300	1.5	66.7	8,264	17,135	191.7	0.0	3689	83
56	202	B13	50.6	26,400	31.9	30.5	14,475	14,854	189.2	0.0	4186	90
57	203	A60	67.5	24,000	22.5	26.3	14,126	14,577	192.5	78.8	2681	77
57	203	A60	67.9	24,000	56.3	0.0	16,388	10,637	193.8	83.2	2720	78
58	203	A61	.1	26,000	25.0	29.0	14,843	14,858	189.8	0.0	307	56
58	203	A61	.6	26,000	2.5	51.3	12,471	16,265	185.1	0.0	307	56
58	203	A61	1.3	26,000	22.5	32.9	14,457	14,577	189.1	0.0	342	56
59	202	A77	28.2	27,400	24.7	5.8	13,421	12,983	186.7	68.4	1867	79
59	202	A77	28.6	27,400	34.8	0.0	14,364	9,942	182.3	47.2	1559	79
59	202	A77	29.4	27,400	79.8	0.0	16,139	10,760	180.4	6.2	1246	78
59	202	A77	29.6	27,300	45.0	45.0	15,252	15,497	186.7	0.0	1138	77
59	202	A77	29.9	27,300	18.9	39.2	14,863	14,094	184.8	0.0	1052	76

Table II is a tabulation of all sample points as related to various flight modes. Figure 50 (see page 42) shows the percentage of time that the torque splits occur in the various flight modes. It was observed that over 50 percent of the torque splits occurred at takeoff or landing.

This set of data samples may or may not be representative of normal mission assignments for the CH-54A. It would be advisable to compare the mission spectrum from which the foregoing samples were collected with that of a larger time history before reaching any firm conclusions about engine load sharing.

TABLE II

TABULATION OF FLIGHT MODES DURING TORQUE SPLITS

Sample No.	Condition	Sample No.	Condition	Sample No.	Condition
1	T	21	C	41	H
2	T	22	L	42	C
3	T	23	T	43	C
4	C	24	C	44	C
5	T	25	T	45	L
6	H	26	T	46	C
7	C	27	H	47	L
8	H	28	H	48	T
9	H	29	C	49	L
10	L	30	C	50	L
11	L	31	T	51	L
12	C	32	L	52	T
13	C	33	T	53	C
14	L	34	T	54	C
15	C	35	L	55	H
16	C	36	T	56	L
17	C	37	C	57	C
18	C	38	C	58	H
19	T	39	T	59	L
20	L	40	L		

T - Takeoff; L - Landing; C - Cruise; H - Hover

CONCLUSIONS

It is concluded that:

1. Torque splits of 40 percent or greater occur frequently enough to justify further study.

2. Torque splitting occurs most frequently during takeoffs and landings, which are the critical flight times.

3. There exists a correlation between gas producer rpm and engine torque splitting.

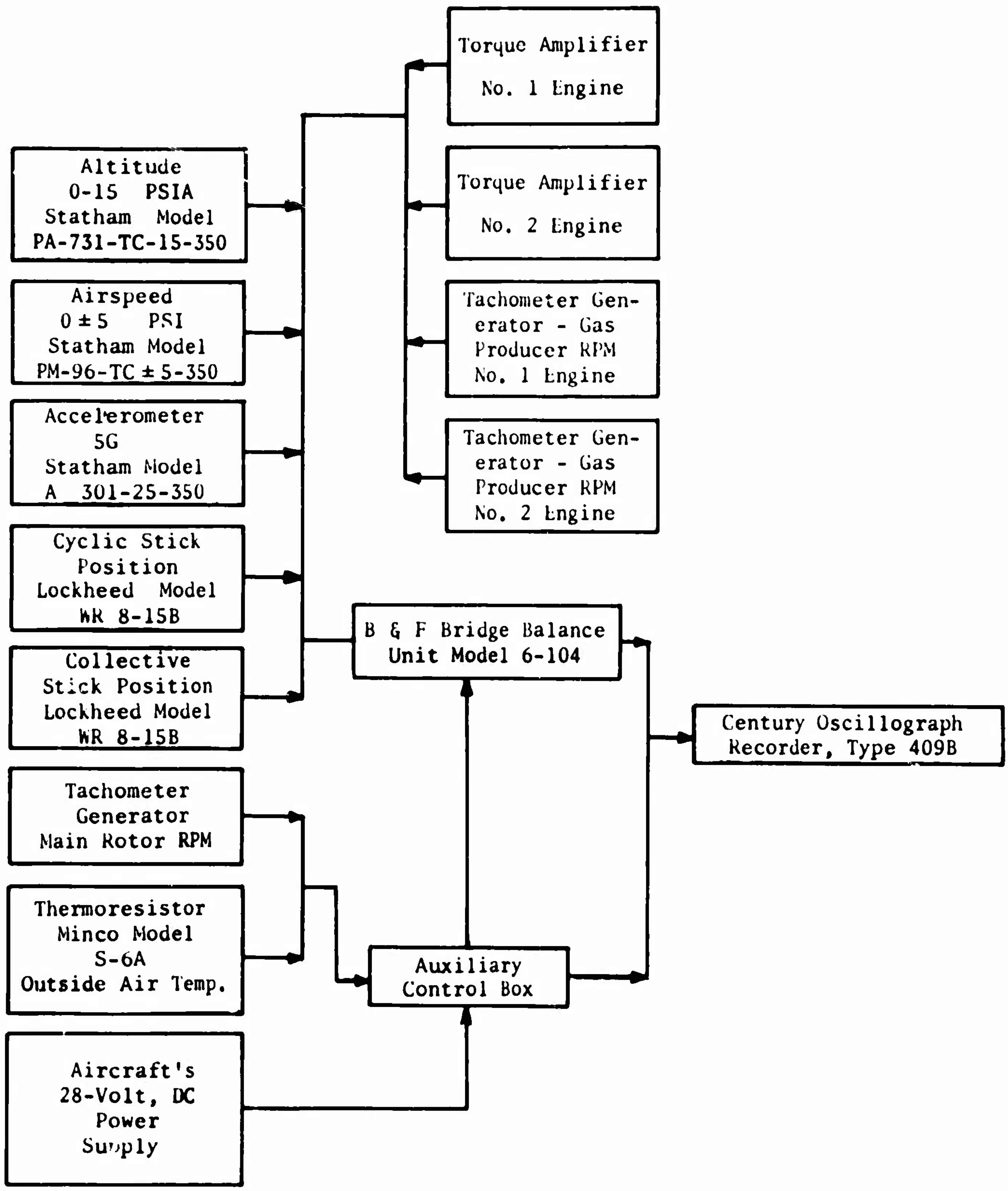

Figure 1. Block Diagram of CH-54A Instrumentation System.

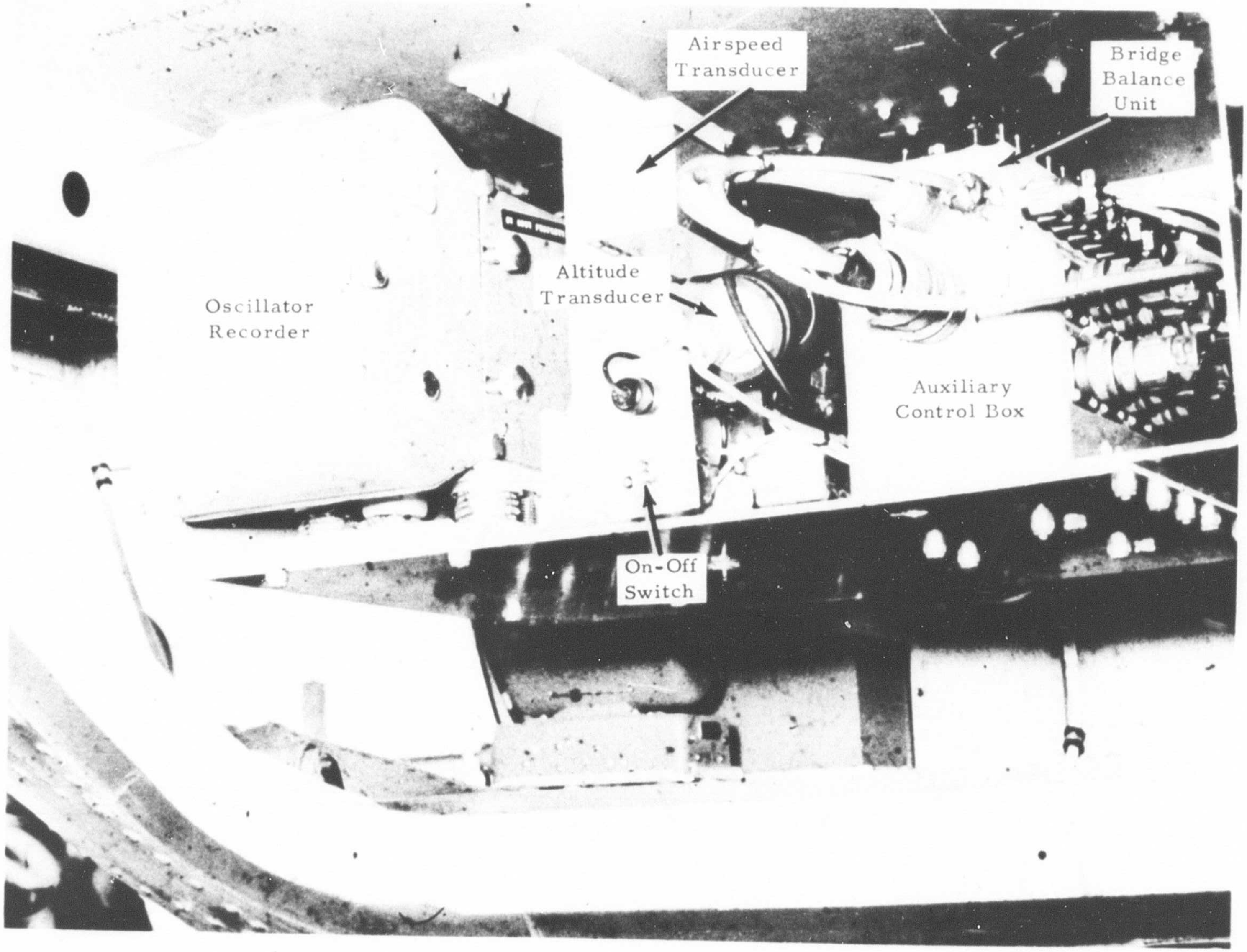

Figure 2. Recorder Installed in CH-54A.

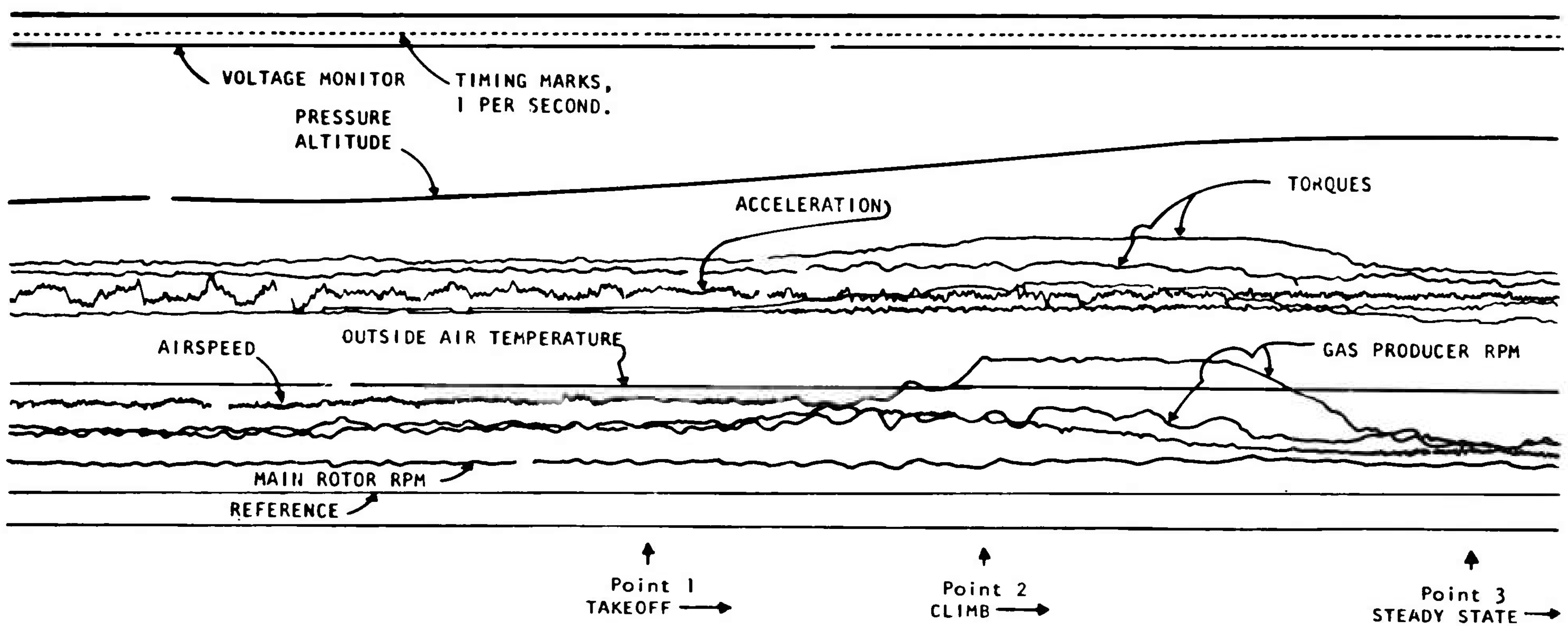

Figure 3. Sample Oscillograph Record.

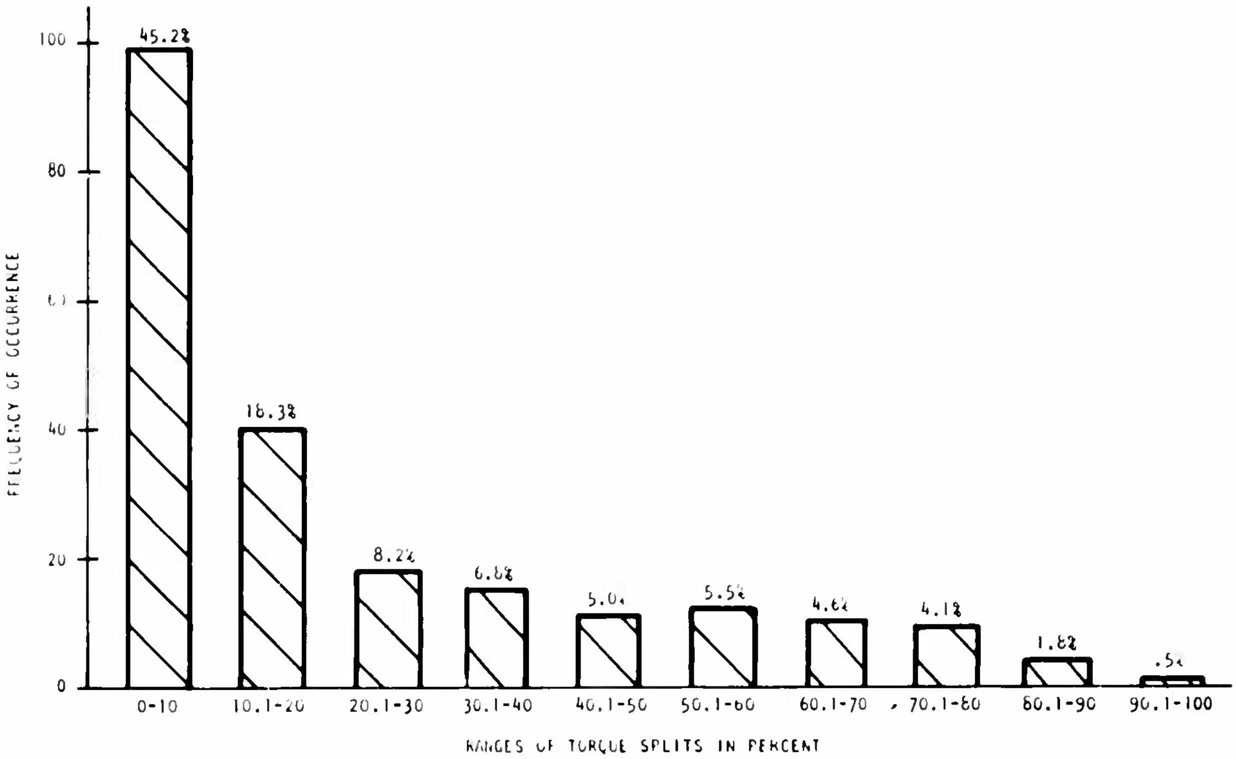

Figure 4. Summary: Torque Splits Versus Frequency of Occurrence (219 Sample Points).

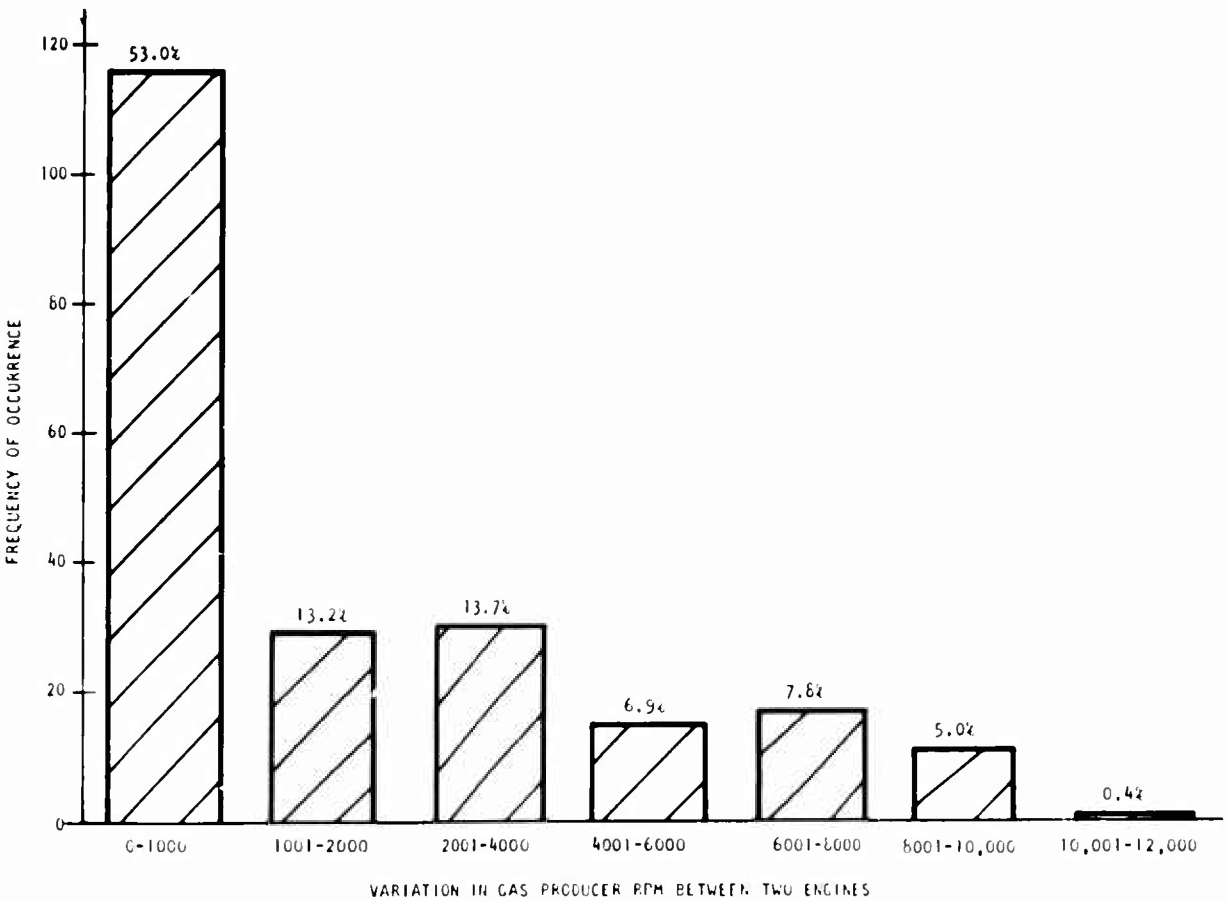

Figure 5. Summary: Gas Producer RPM Versus Frequency of Occurrence (219 Sample Points).

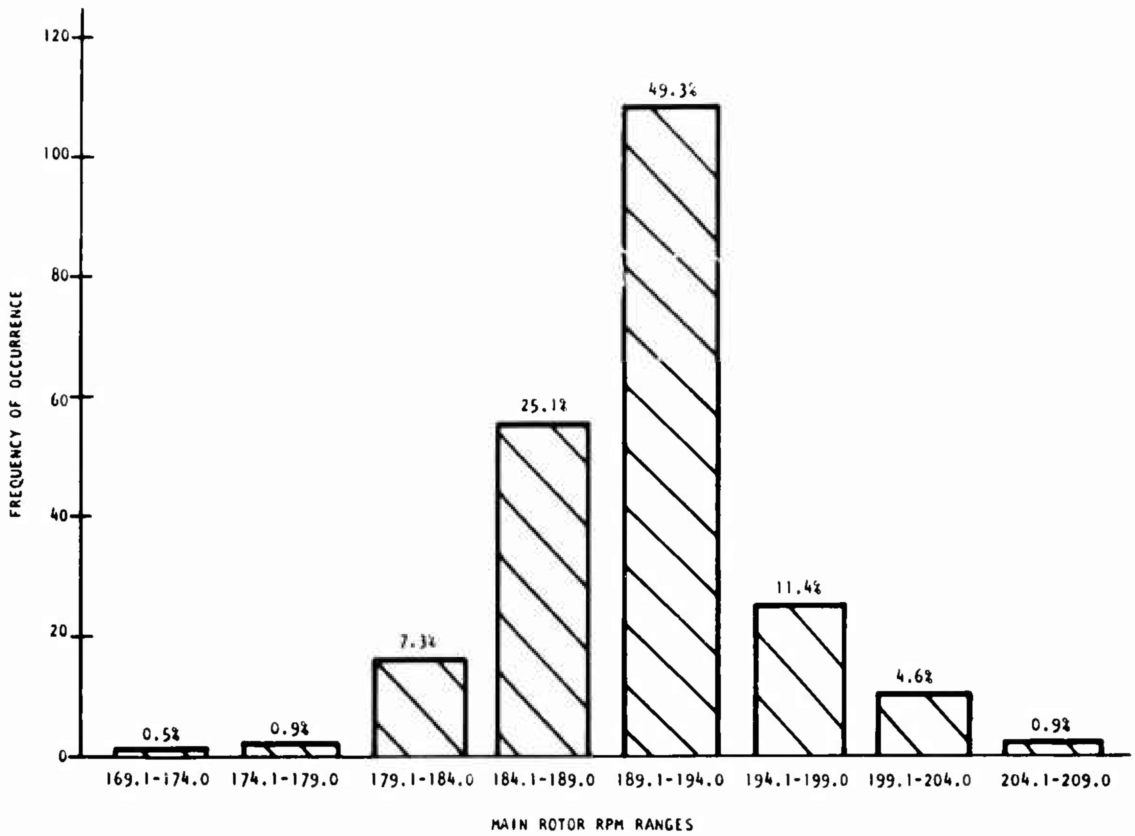

Figure 6. Summary: Main Rotor RPM Versus Frequency of Occurrence (219 Sample Points).

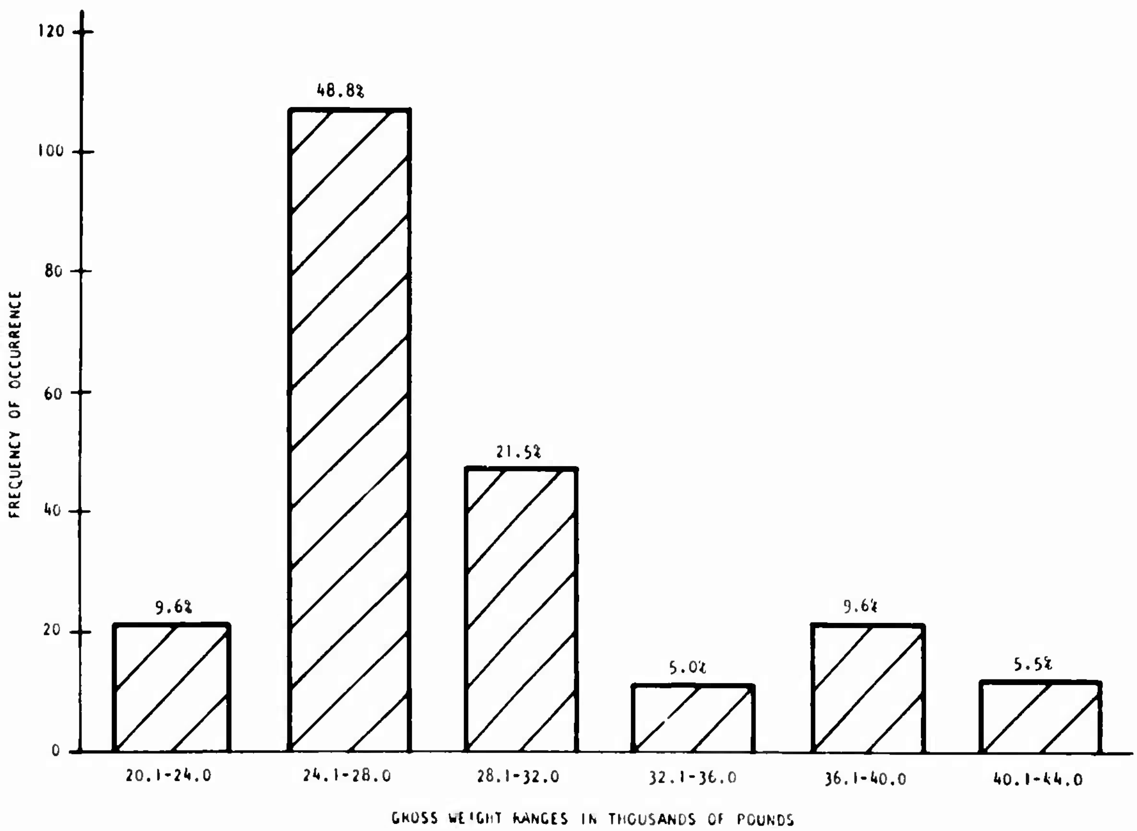

Figure 7. Summary: Gross Weight Versus Frequency of Occurrence (219 Sample Points).

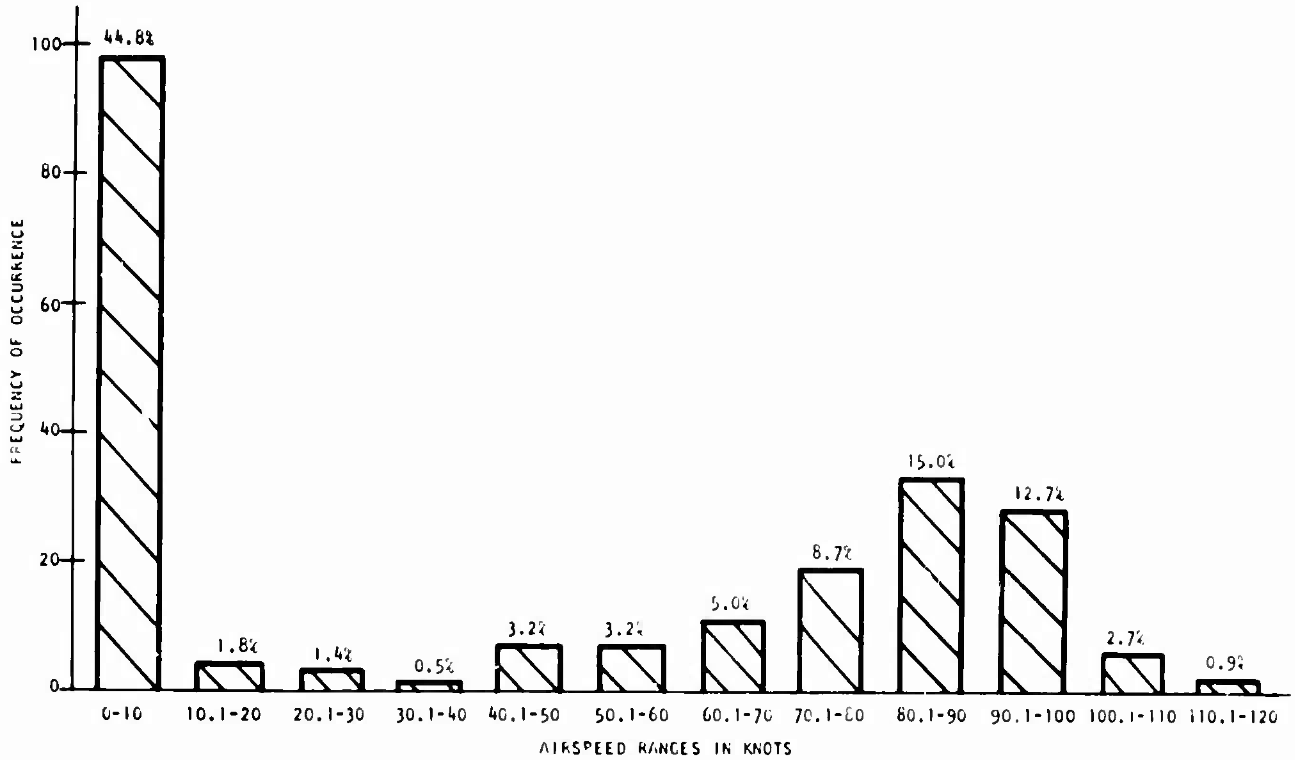

Figure 8. Summary: Airspeed Versus Frequency of Occurrence (219 Sample Points).

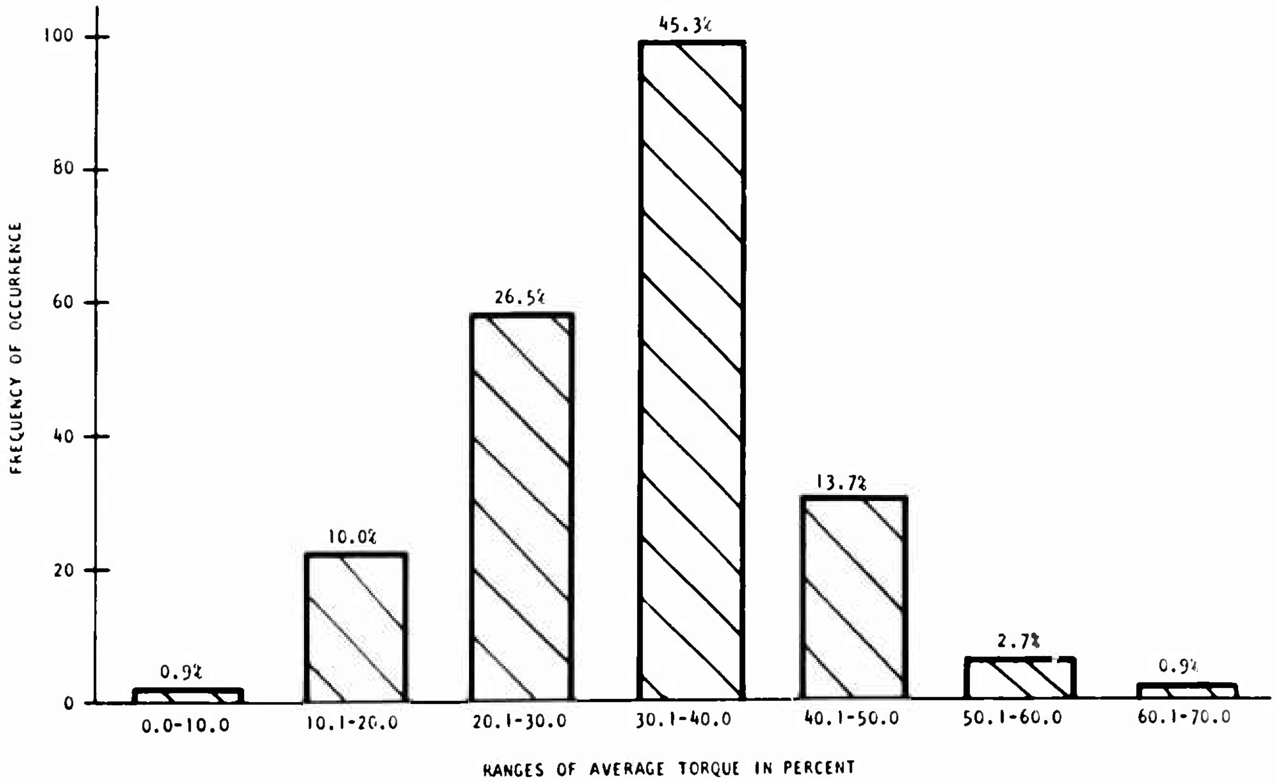

Figure 9. Summary: Average Torque per Engine Versus Frequency of Occurrence (219 Sample Points).

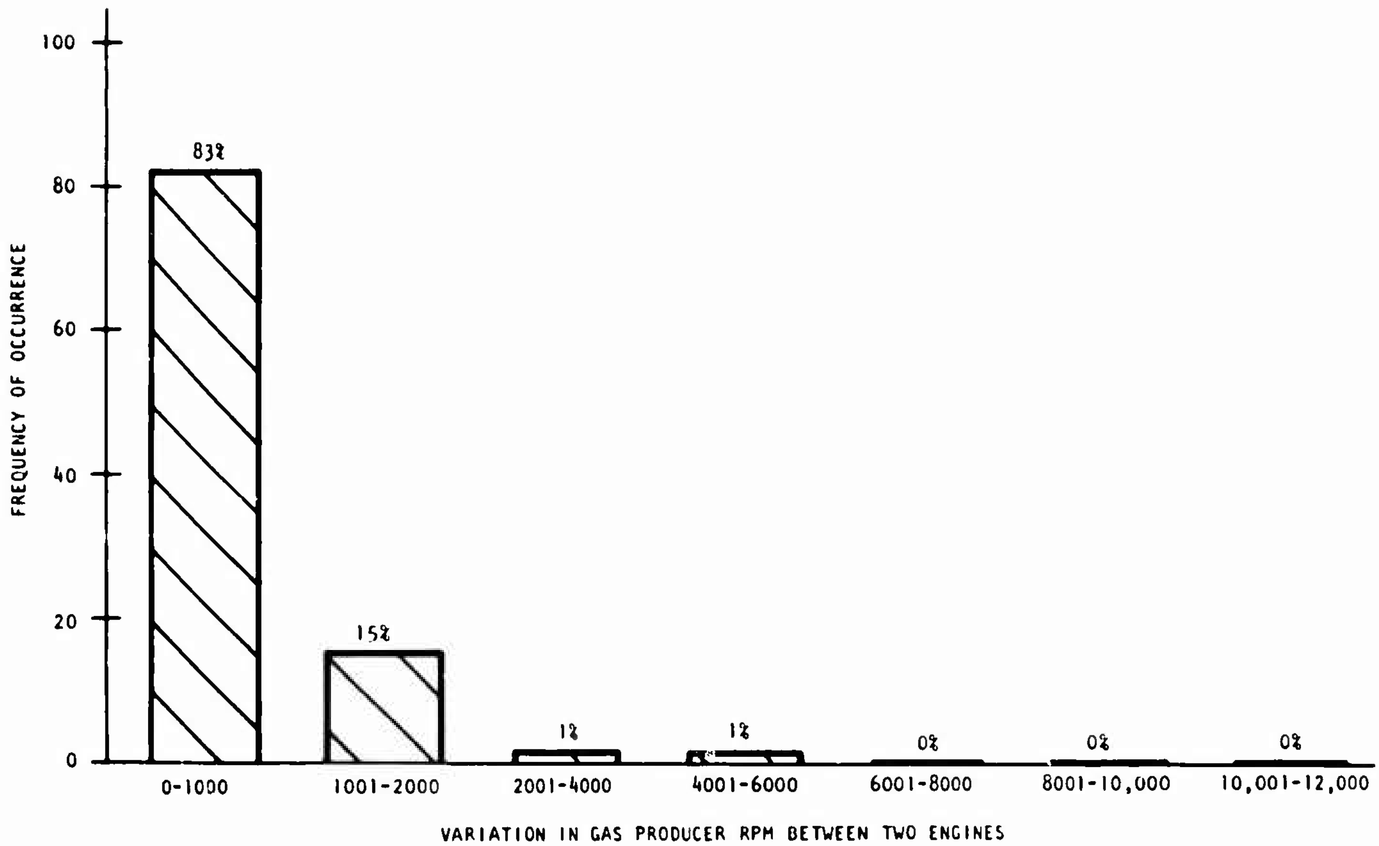

Figure 10. Gas Producer RPM Versus Frequency of Occurrence at 0- to 10-Percent Torque Split (99 Sample Points).

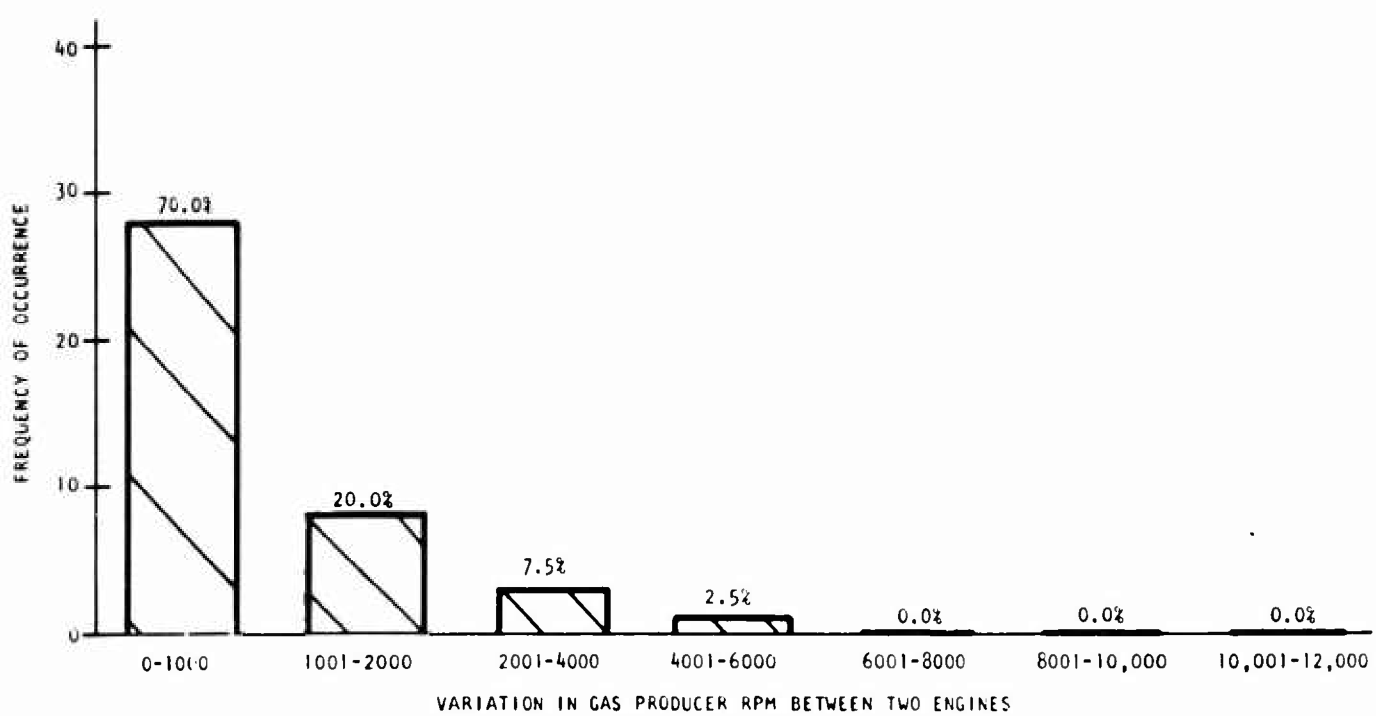

Figure 11. Gas Producer RPM Versus Frequency of Occurrence at 10- to 20-Percent Torque Split (40 Sample Points).

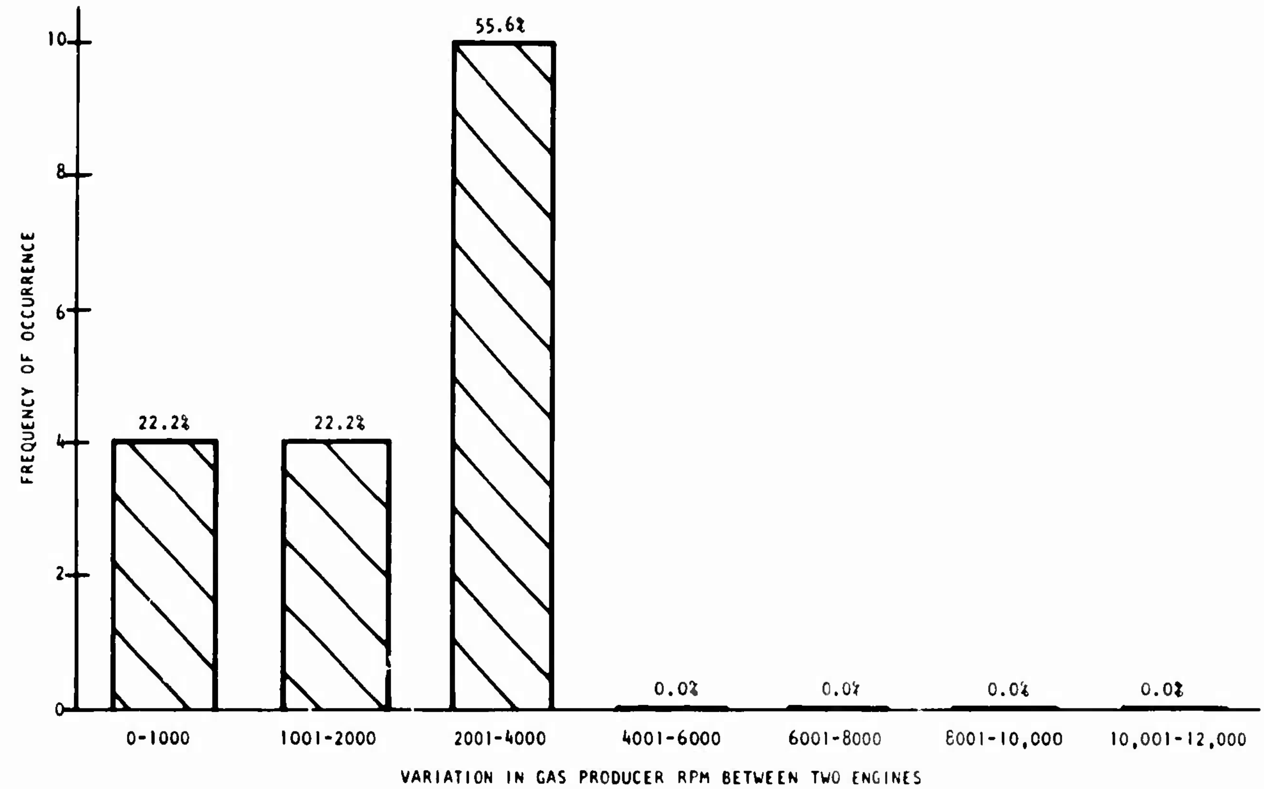

Figure 12. Gas Producer RPM Versus Frequency of Occurrence at 20- to 30-Percent Torque Split (18 Sample Points).

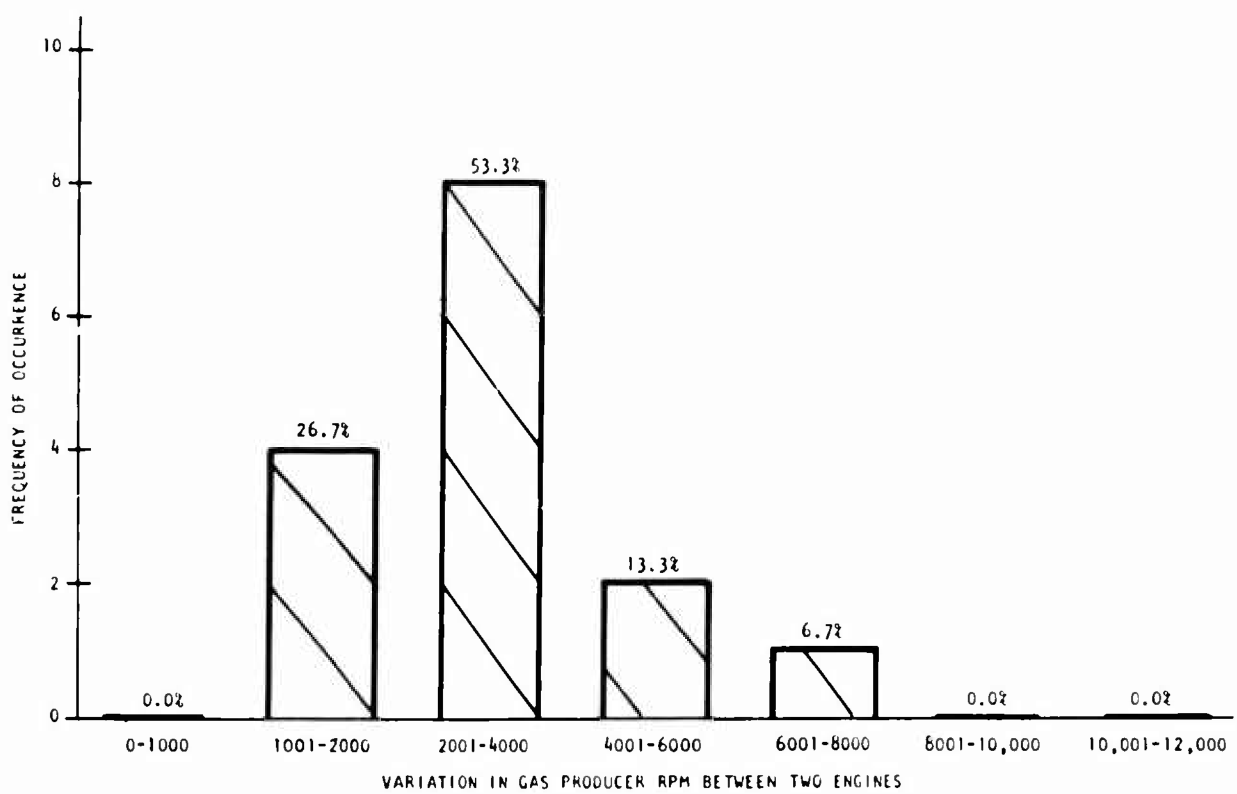

Figure 13. Gas Producer RPM Versus Frequency of Occurrence at 30- to 40-Percent Torque Split (15 Sample Points).

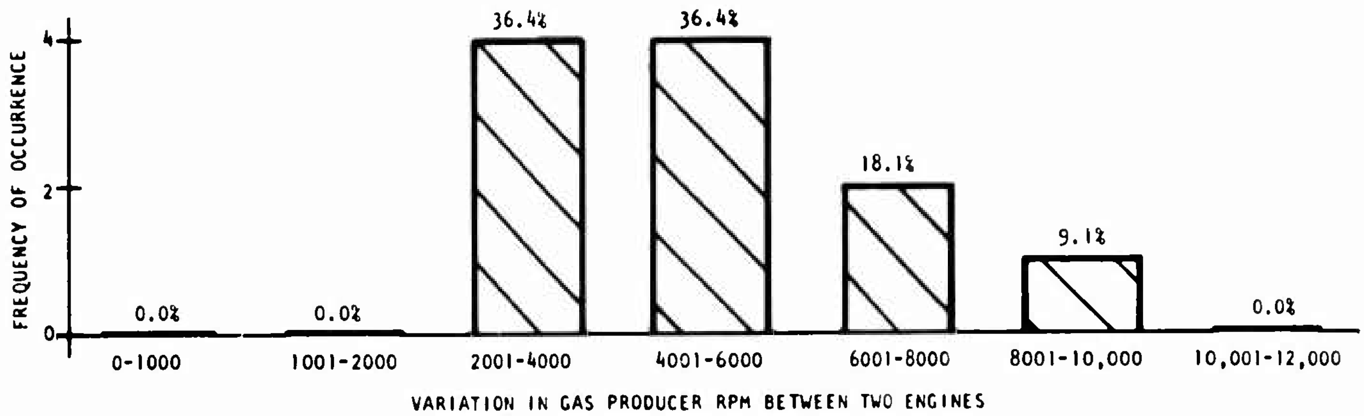

Figure 14. Gas Producer RPM Versus Frequency of Occurrence at 40- to 50-Percent Torque Split (11 Sample Points).

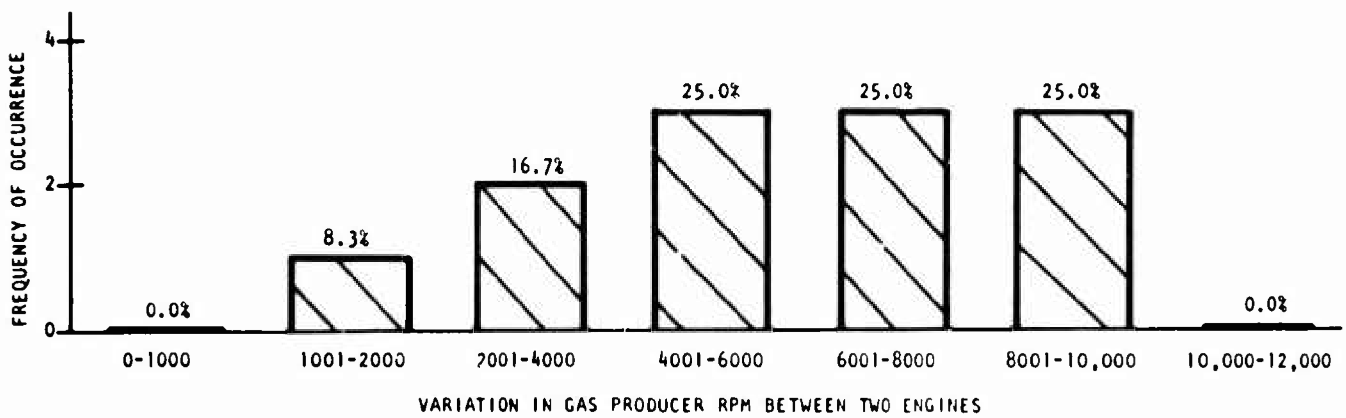

Figure 15. Gas Producer RPM Versus Frequency of Occurrence at 50- to 60-Percent Torque Split (12 Sample Points).

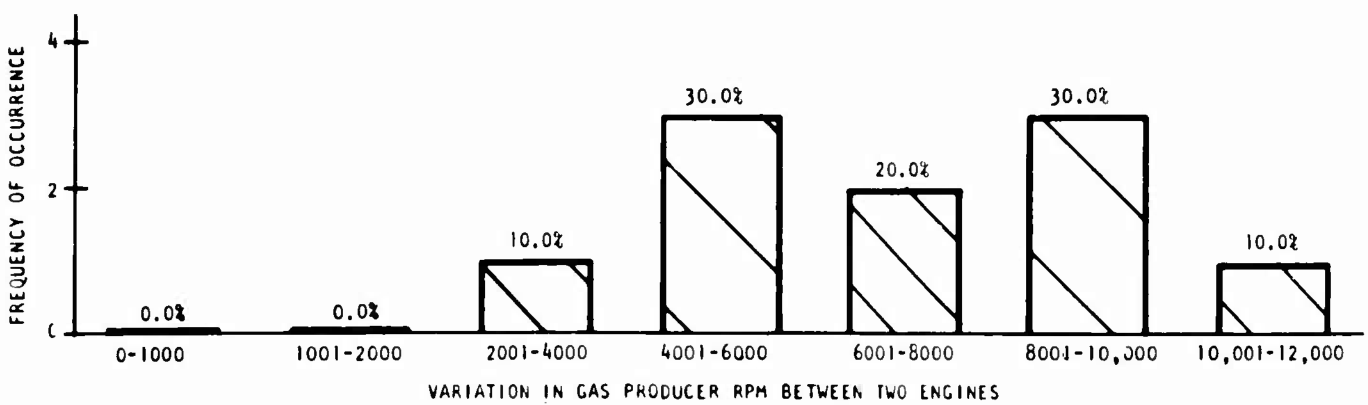

Figure 16. Gas Producer RPM Versus Frequency of Occurrence at 60- to 70-Percent Torque Split (10 Sample Points).

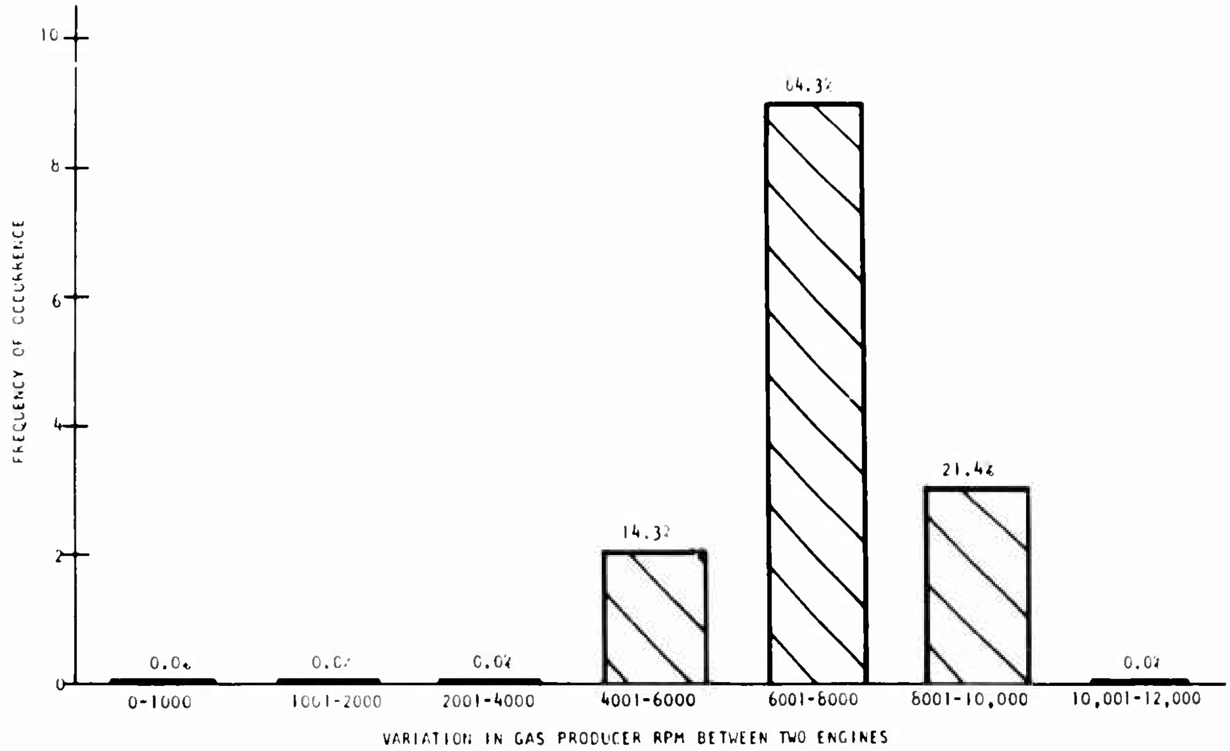

Figure 17. Gas Producer RPM Versus Frequency of Occurrence at 70- to 100-Percent Torque Split (14 Sample Points).

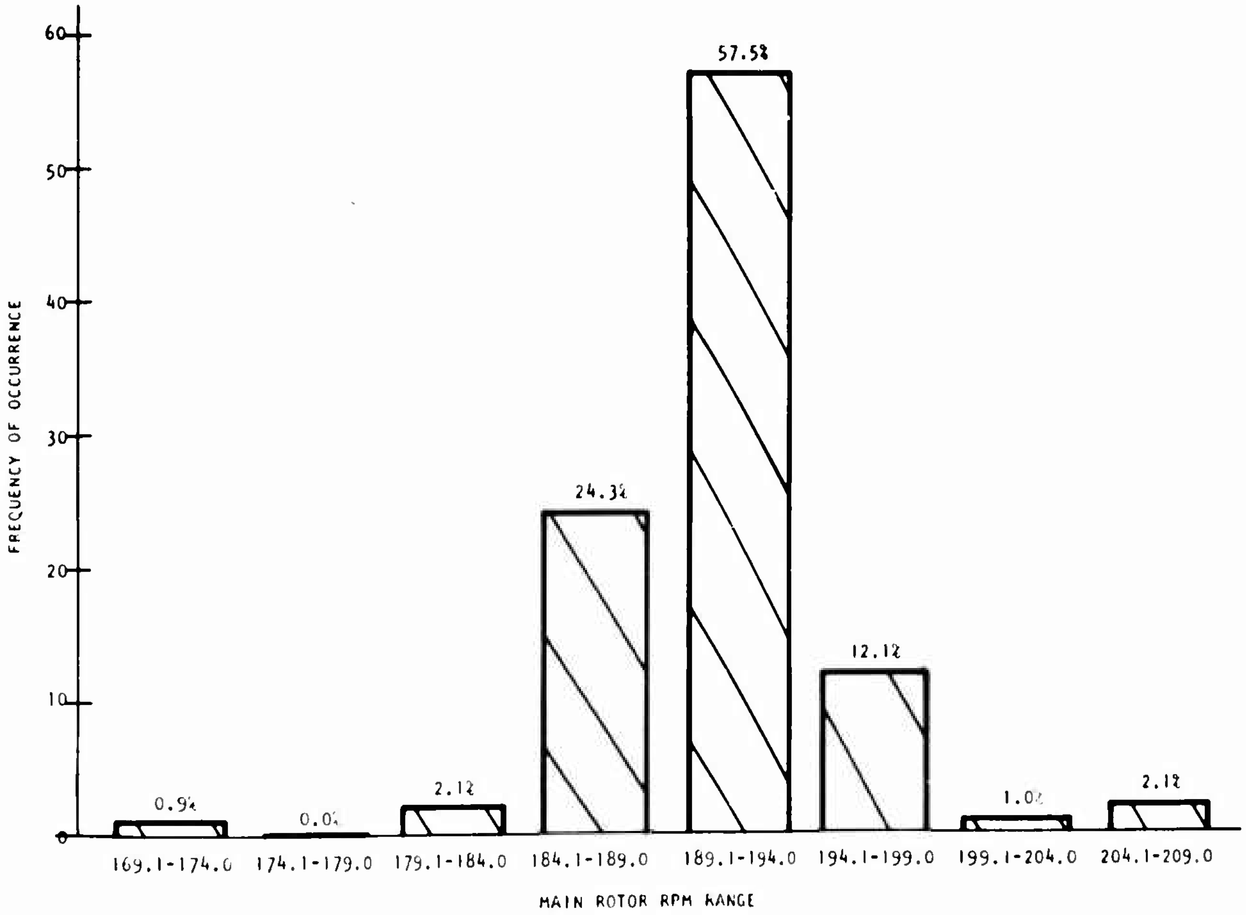

Figure 18. Main Rotor RPM Versus Frequency of Occurrence at 0- to 10-Percent Torque Split (99 Sample Points).

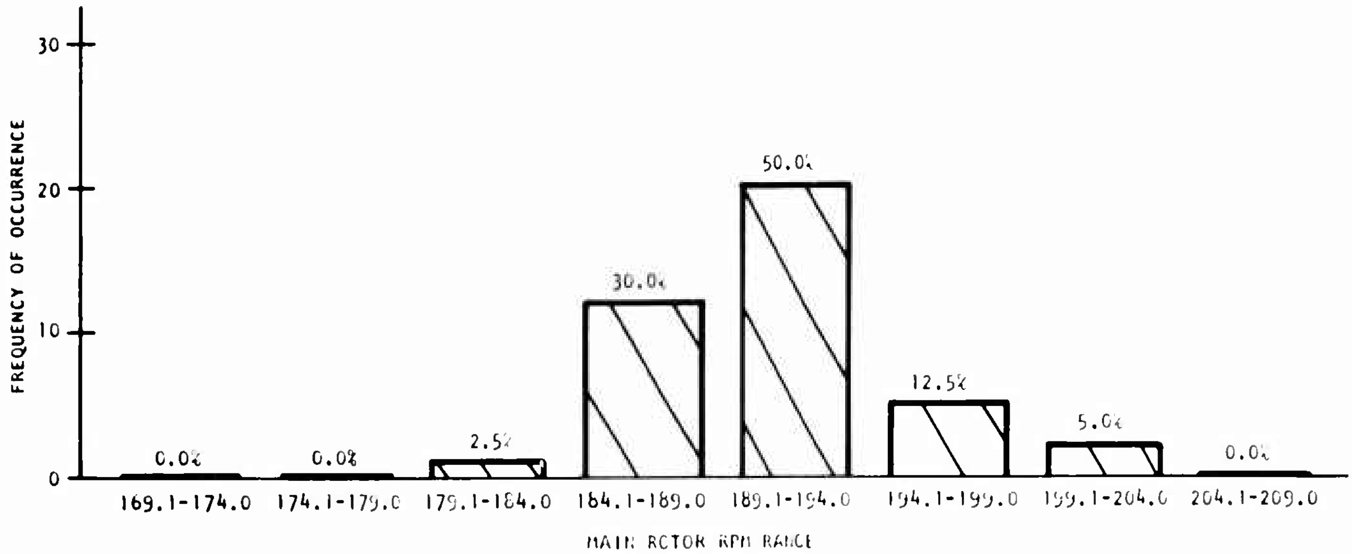

Figure 19. Main Rotor RPM Versus Frequency of Occurrence at 10- to 20-Percent Torque Split (40 Sample Points).

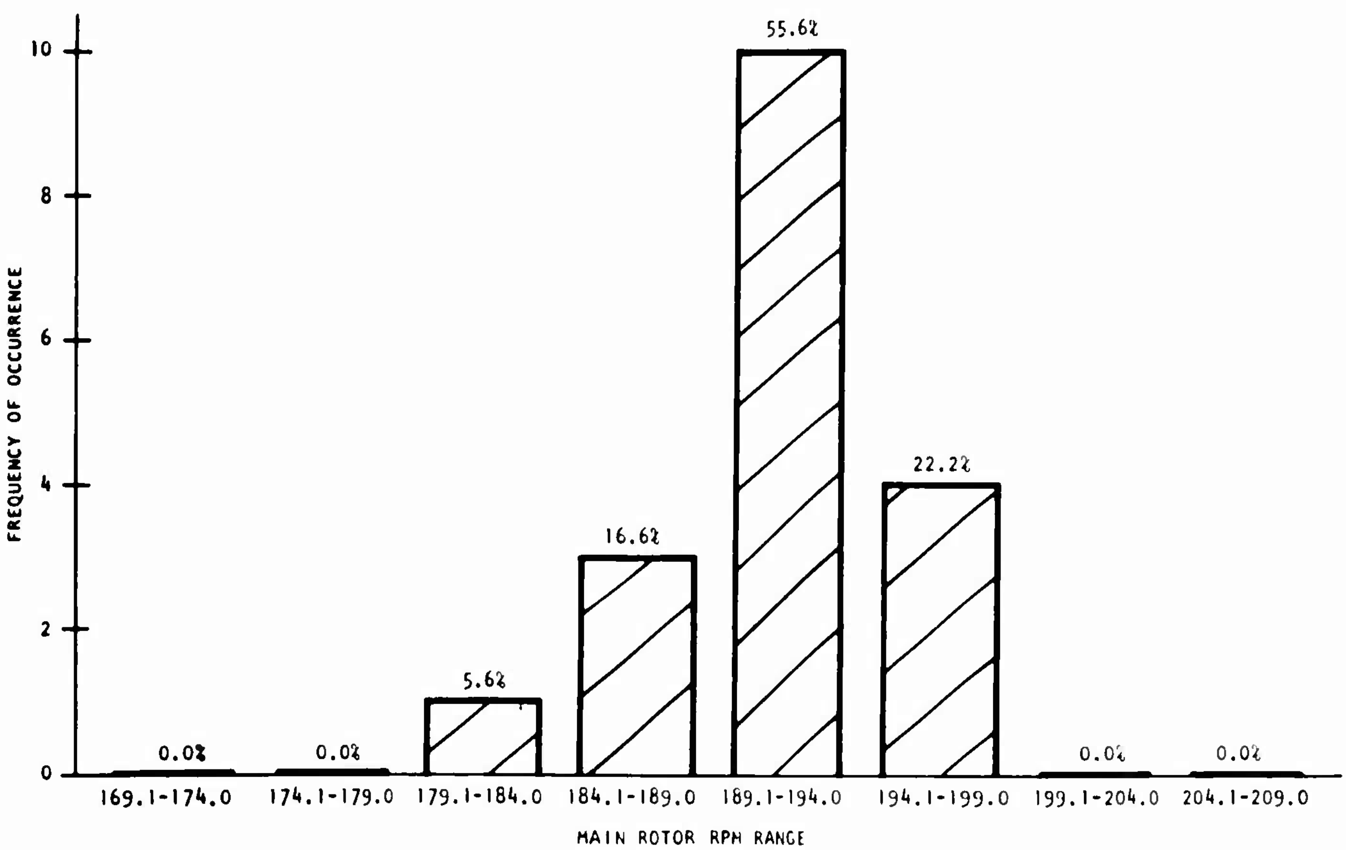

Figure 20. Main Rotor RPM Versus Frequency of Occurrence at 20- to 30-Percent Torque Split (18 Sample Points).

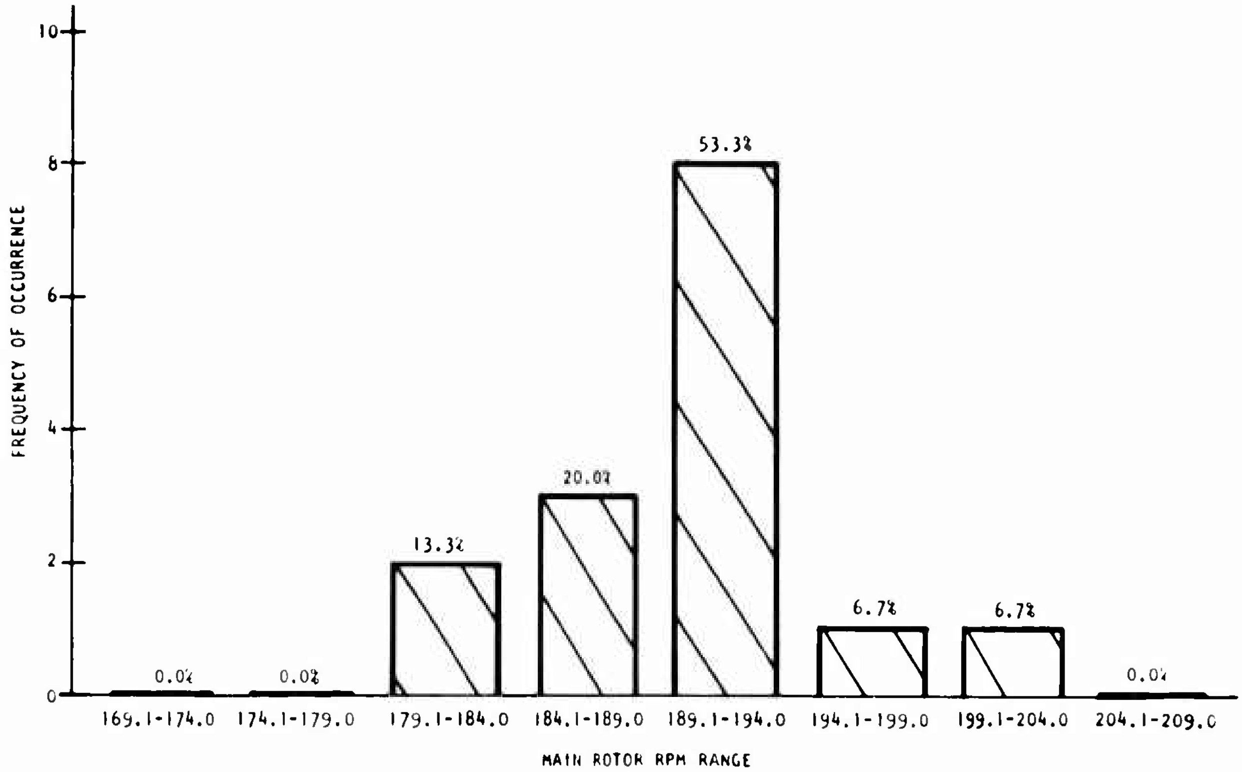

Figure 21. Main Rotor RPM Versus Frequency of Occurrence at 30- to 40-Percent Torque Split (15 Sample Points).

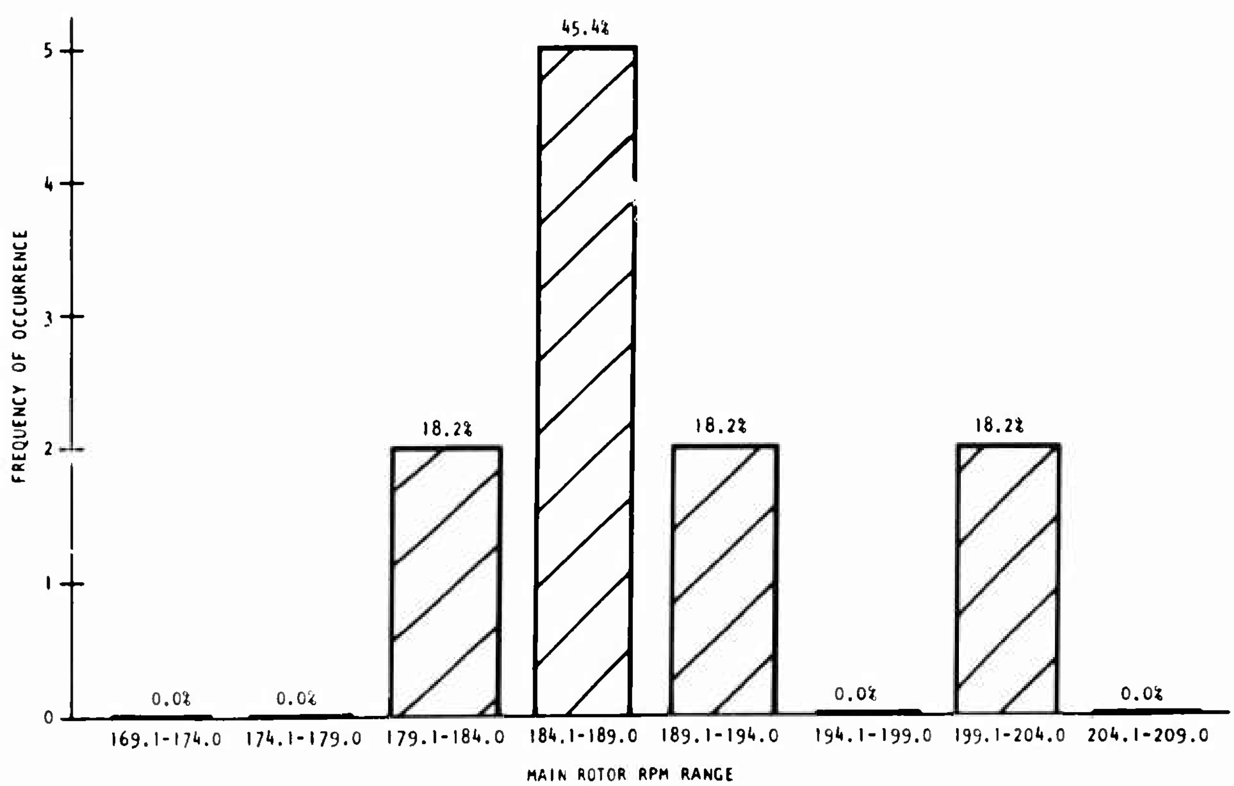

Figure 22. Main Rotor RPM Versus Frequency of Occurrence at 40- to 50-Percent Torque Split (11 Sample Points).

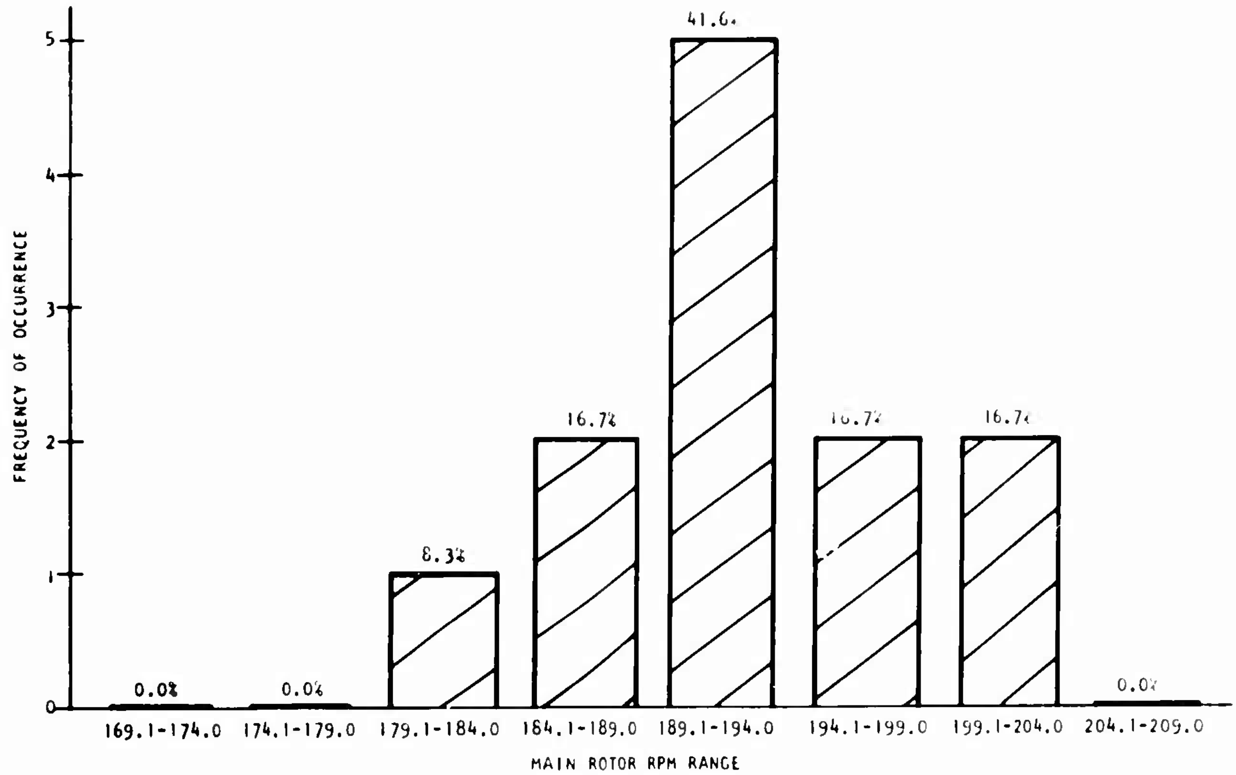

Figure 23. Main Rotor RPM Versus Frequency of Occurrence at 50- to 60-Percent Torque Split (12 Sample Points).

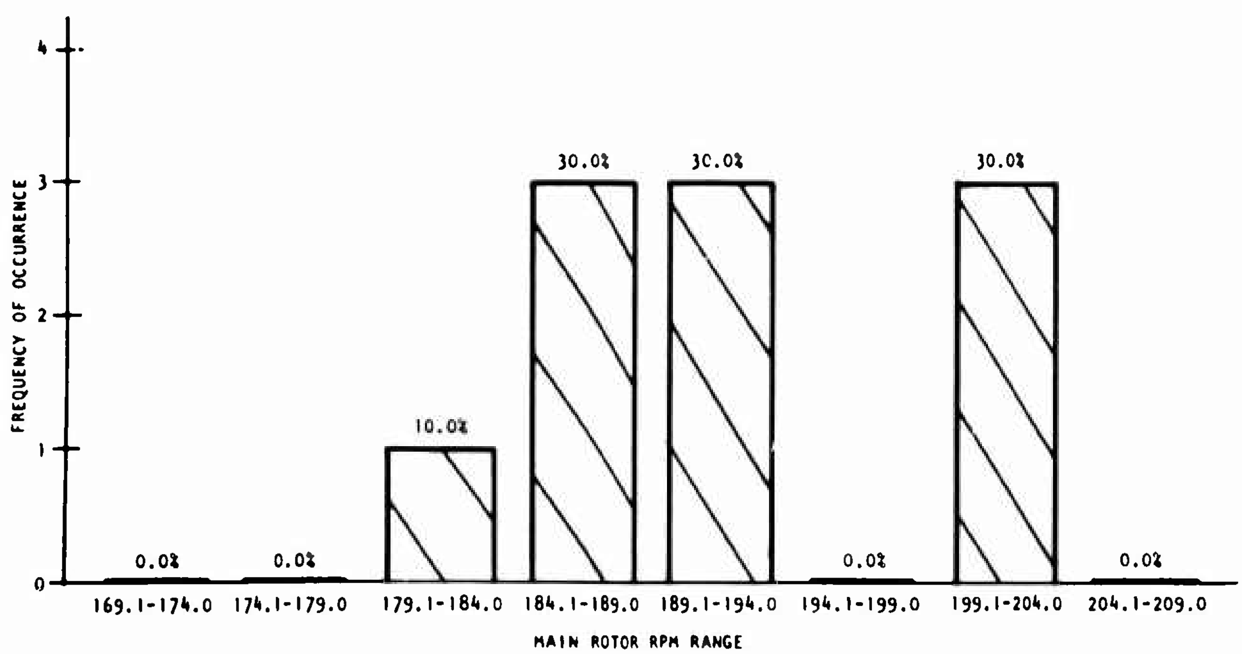

Figure 24. Main Rotor RPM Versus Frequency of Occurrence at 60- to 70-Percent Torque Split (10 Sample Points).

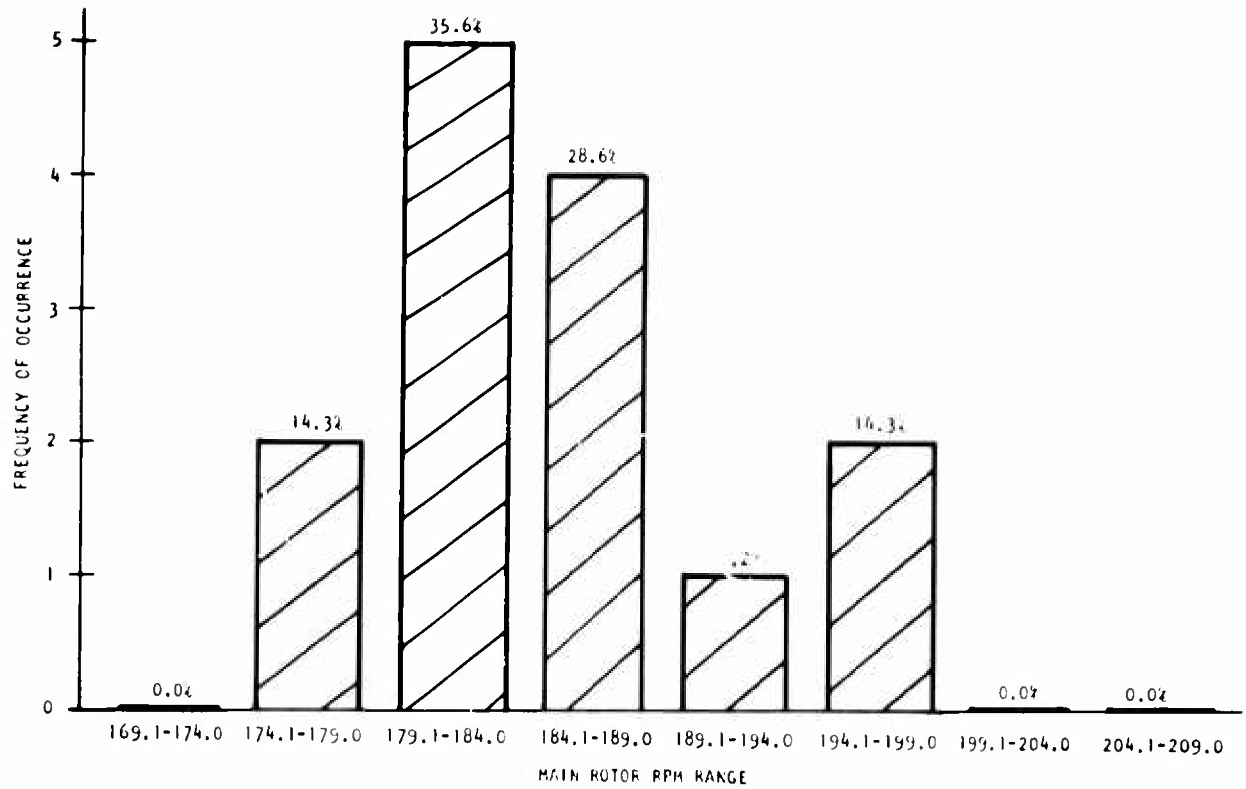

Figure 25. Main Rotor RPM Versus Frequency of Occurrence at 70- to 100-Percent Torque Split (14 Sample Points).

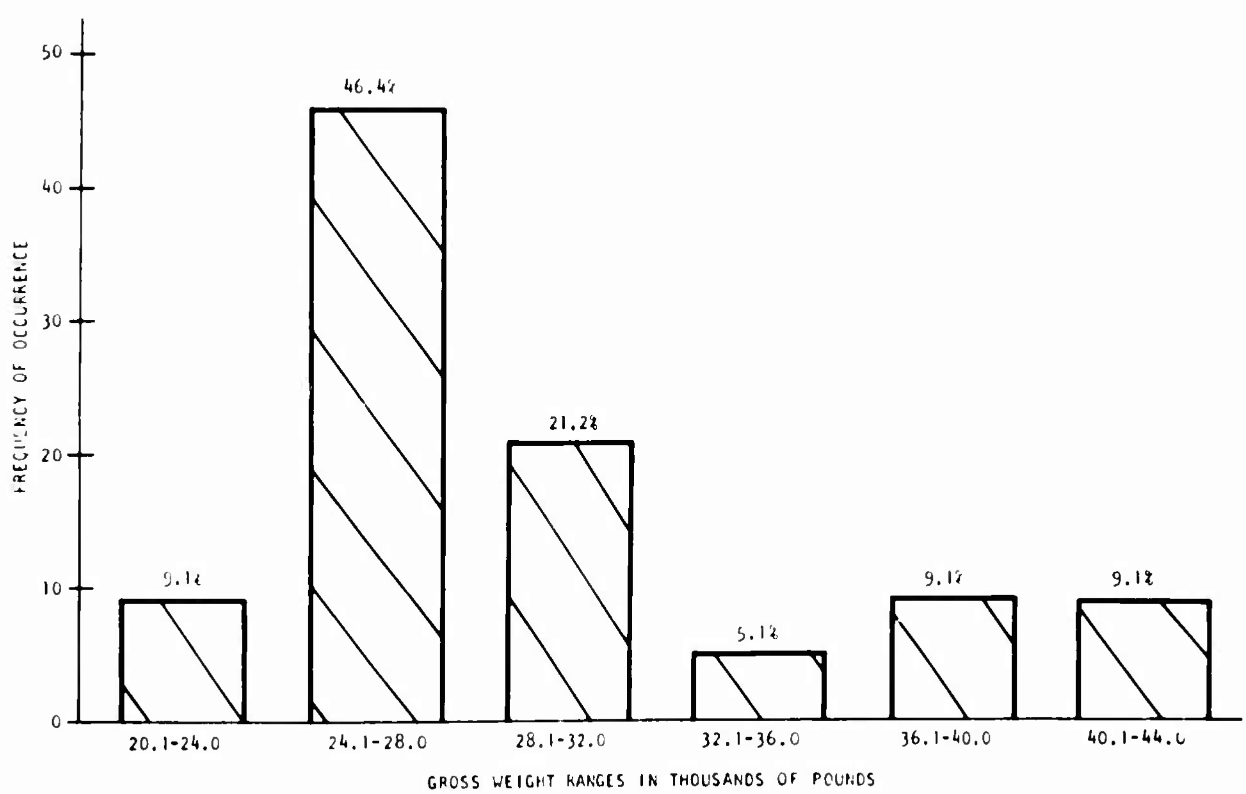

Figure 26. Gross Weight Versus Frequency of Occurrence at 0- to 10-Percent Torque Split (99 Sample Points).

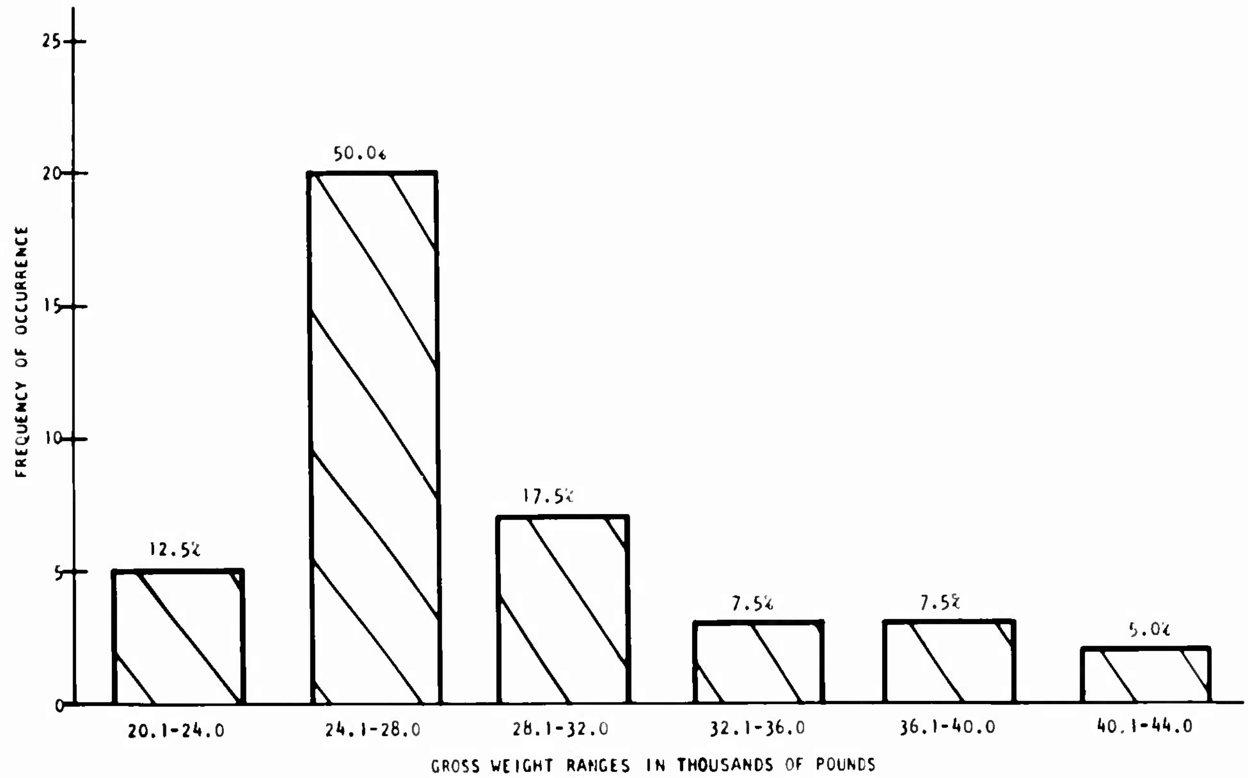

Figure 27. Gross Weight Versus Frequency of Occurrence at 10- to 20-Percent Torque Split (40 Sample Points).

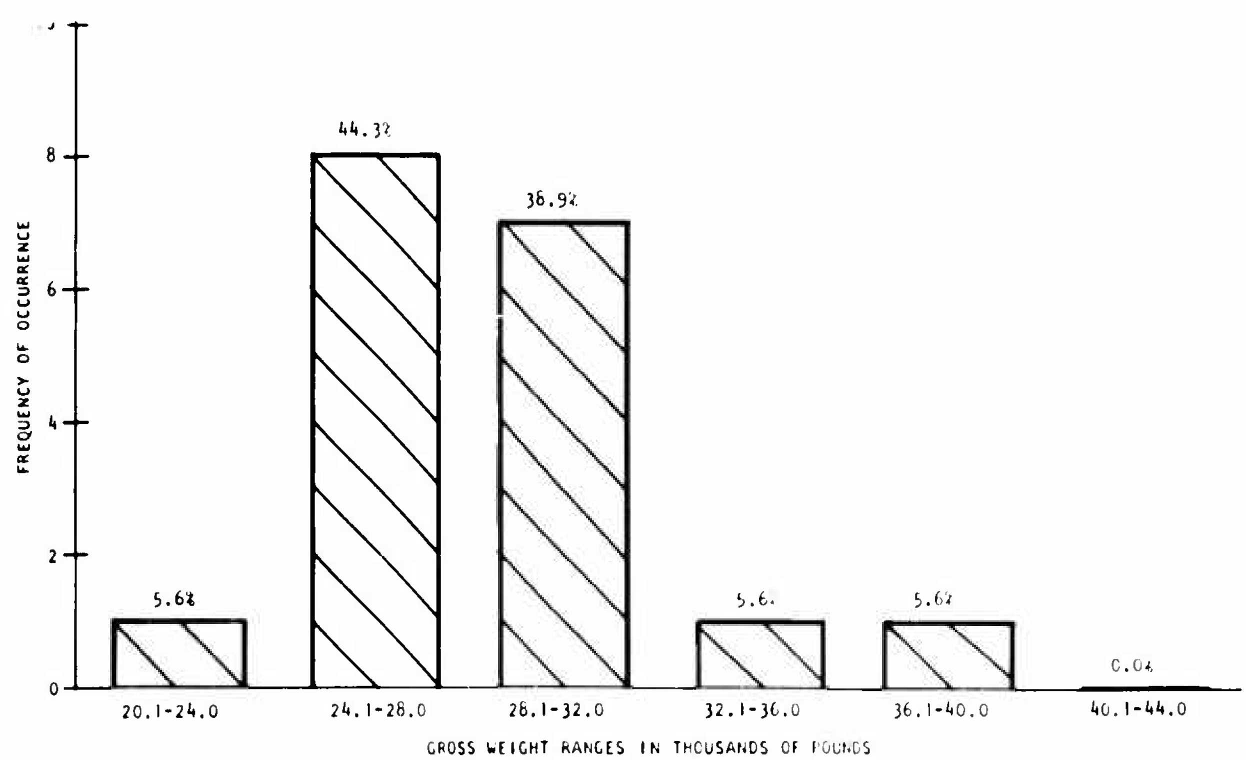

Figure 28. Gross Weight Versus Frequency of Occurrence at 20- to 30-Percent Torque Split (39 Sample Points).

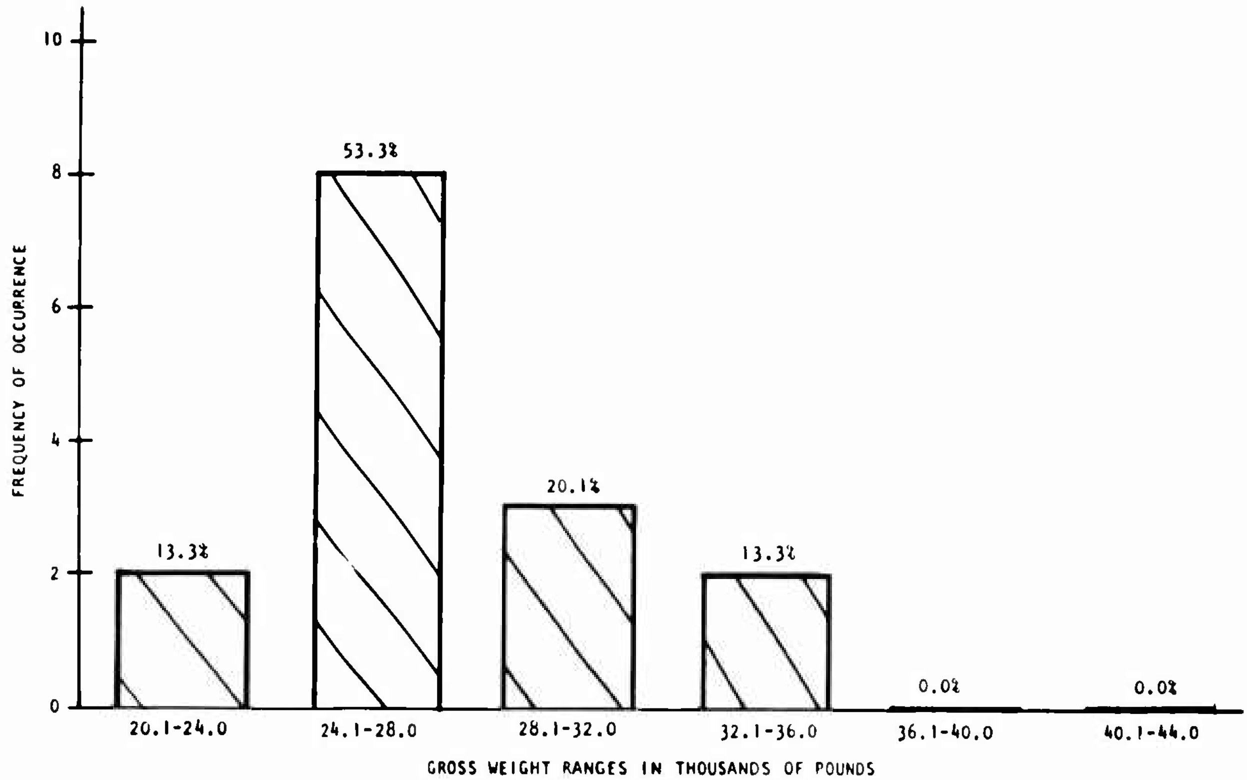

Figure 29. Gross Weight Versus Frequency of Occurrence at 30- to 40-Percent Torque Split (15 Sample Points).

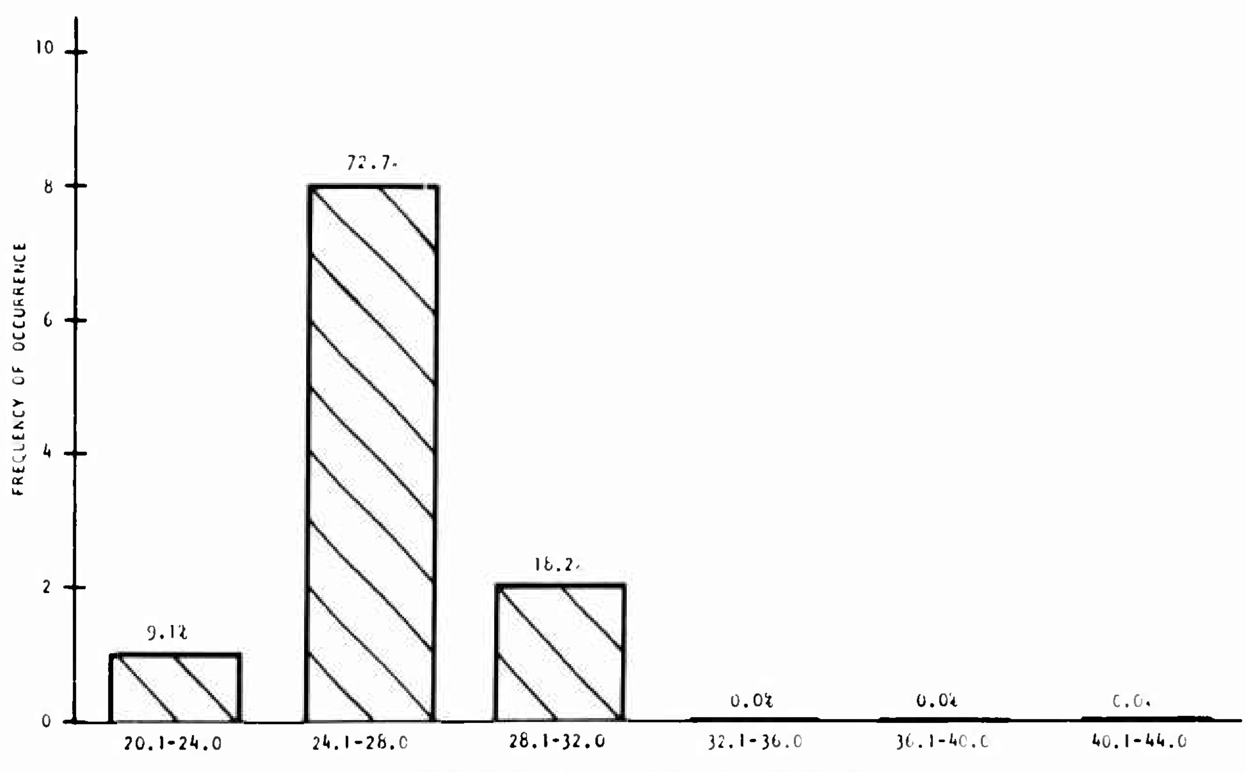

Figure 30. Gross Weight Versus Frequency of Occurrence at 40- to 50-Percent Torque Split (11 Sample Points).

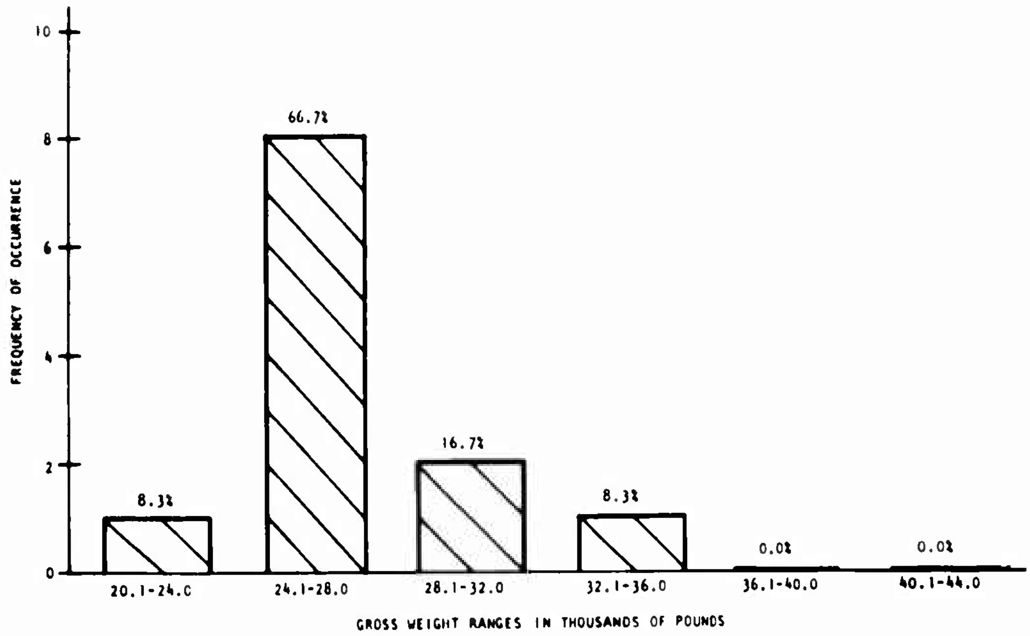

Figure 31. Gross Weight Versus Frequency of Occurrence at 50- to 60-Percent Torque Split (12 Sample Points).

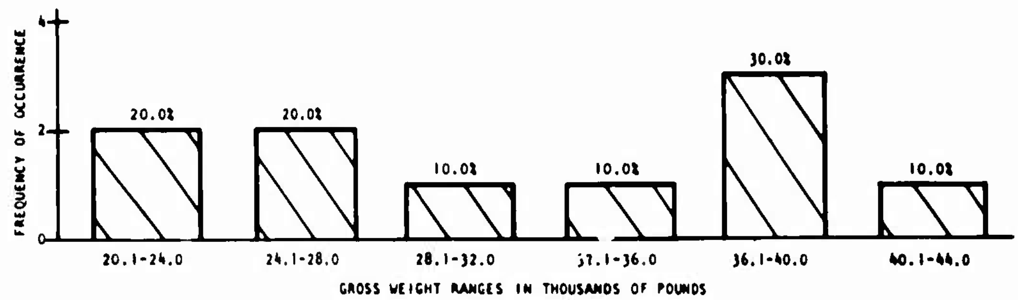

Figure 32. Gross Weight Versus Frequency of Occurrence at 60- to 70-Percent Torque Split (10 Sample Points).

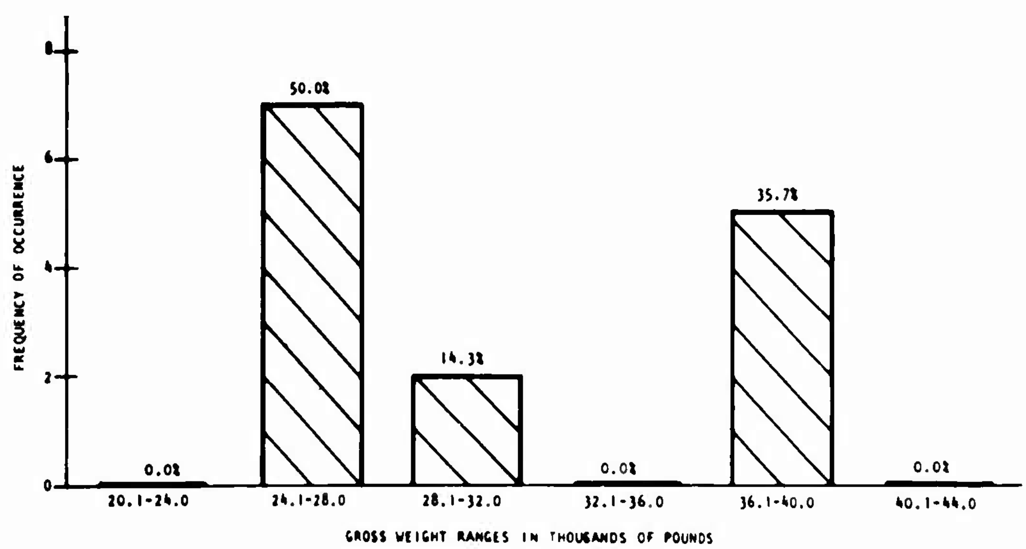

Figure 33. Gross Weight Versus Frequency of Occurrence at 70- to 100-Percent Torque Split (14 Sample Points).

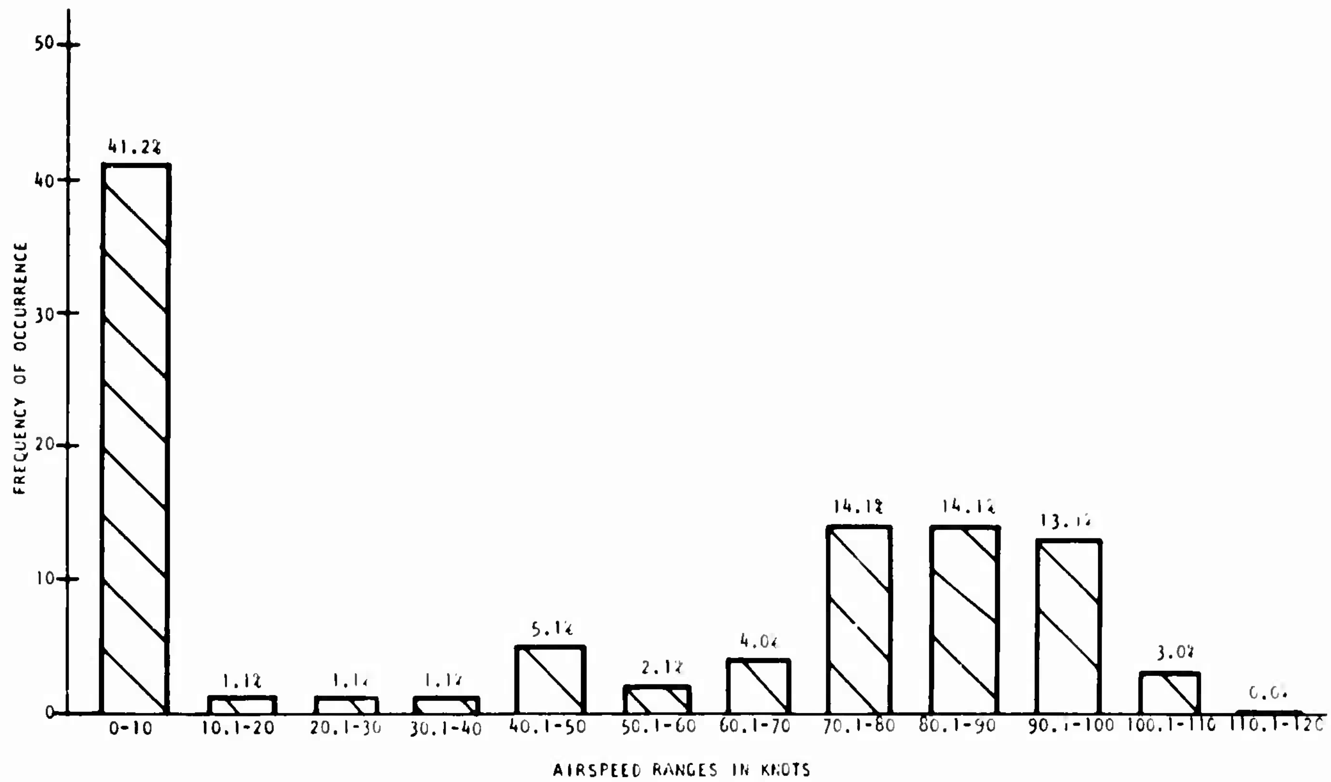

Figure 34. Airspeed Versus Frequency of Occurrence at 0- to 10-Percent Torque Split (99 Sample Points).

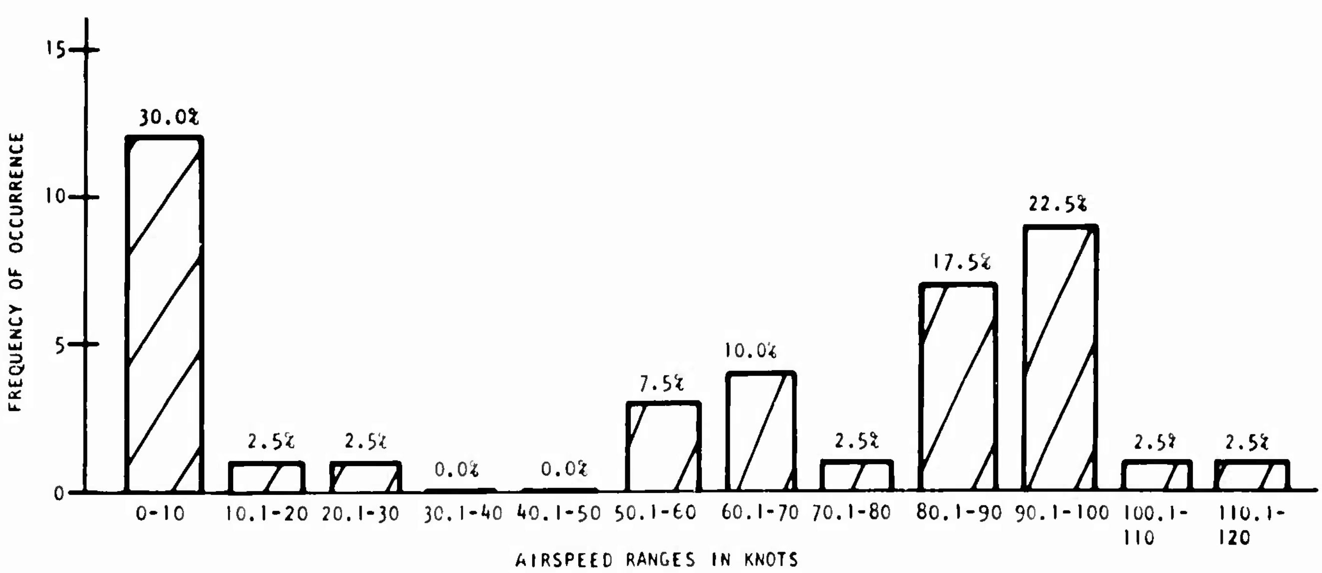

Figure 35. Airspeed Versus Frequency of Occurrence at 10- to 20-Percent Torque Split (40 Sample Points).

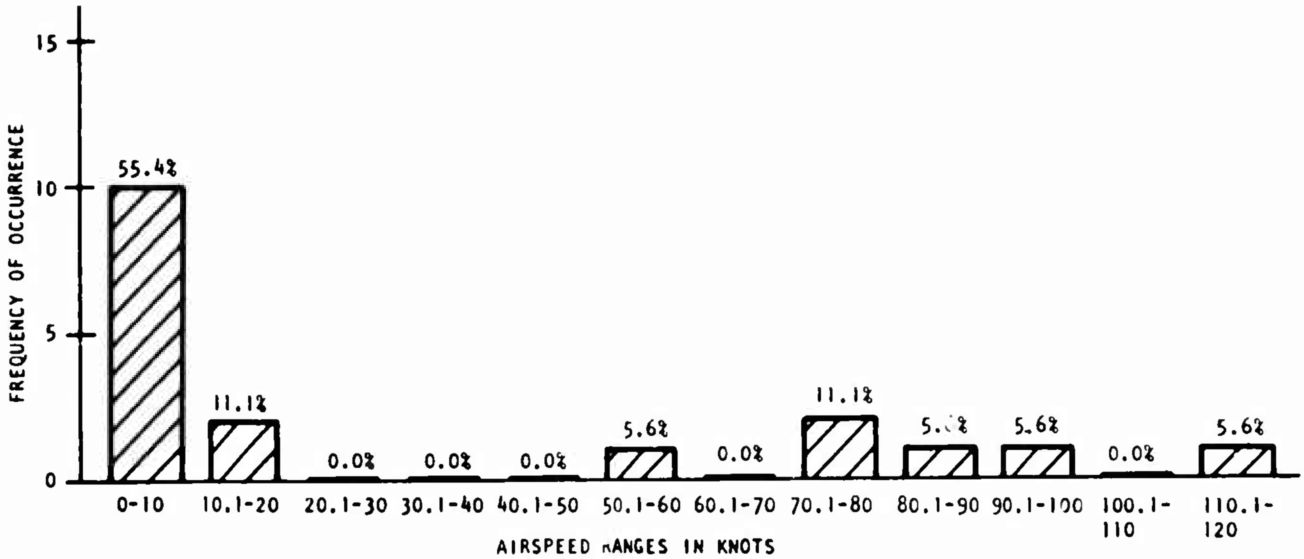

Figure 36. Airspeed Versus Frequency of Occurrence at 20- to 30-Percent Torque Split (18 Sample Points).

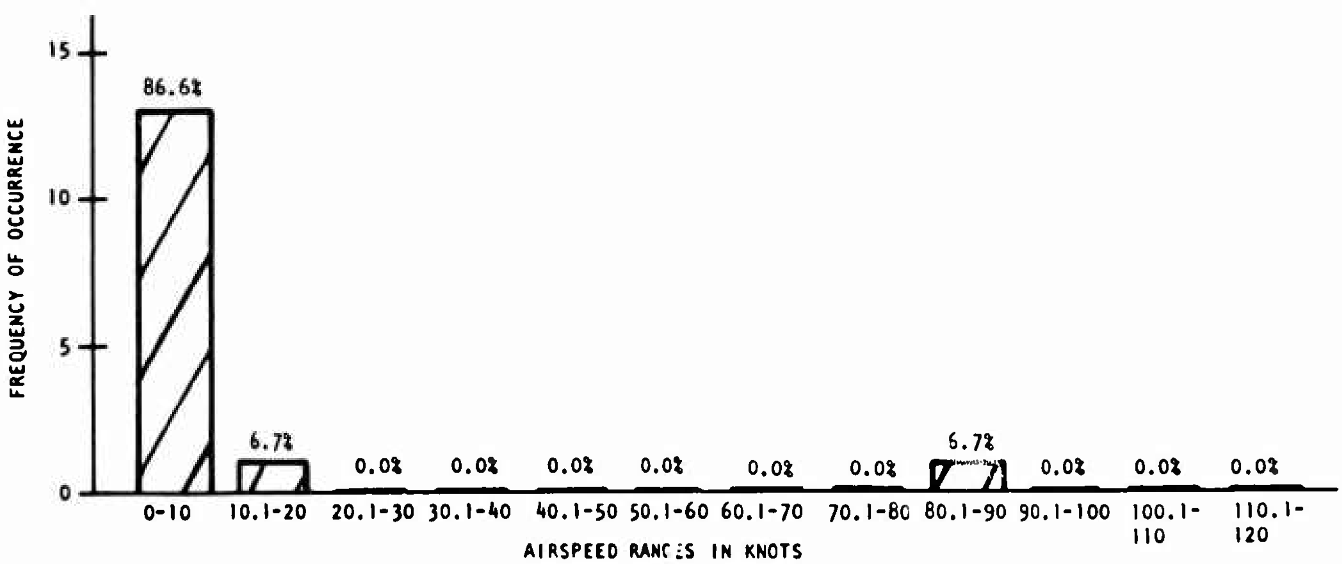

Figure 37. Airspeed Versus Frequency of Occurrence at 30- to 40-Percent Torque Split (15 Sample Points).

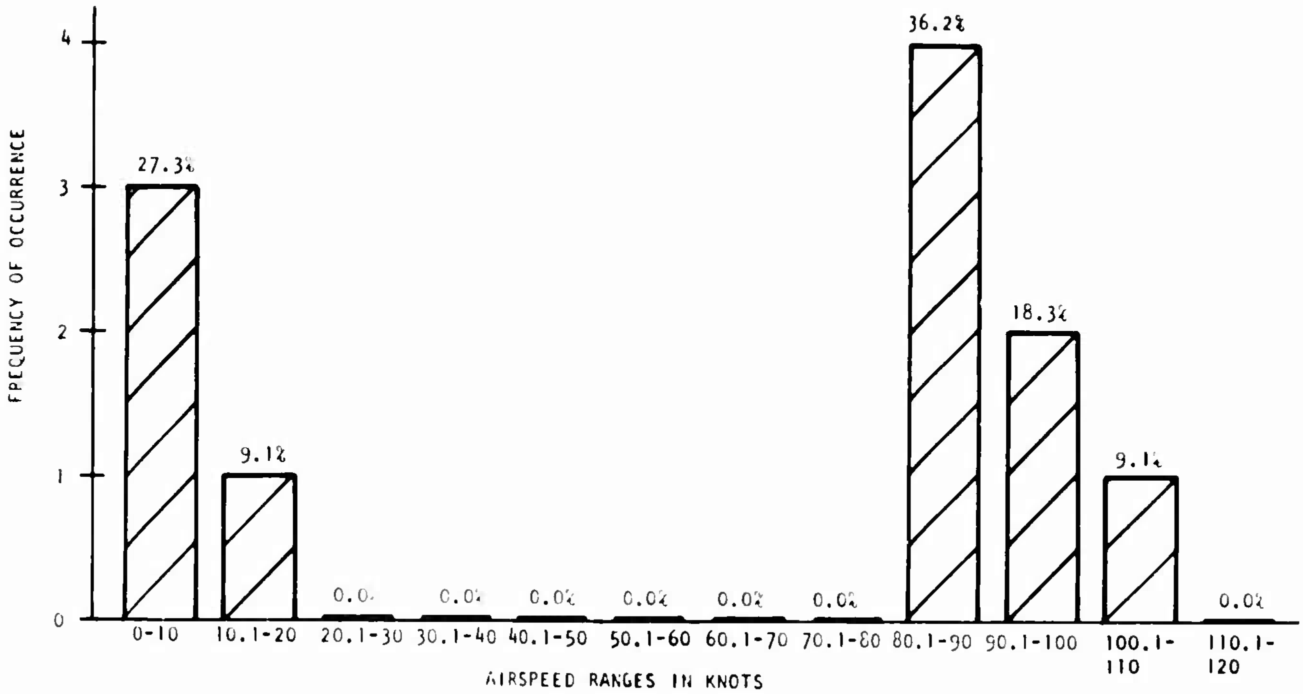

Figure 38. Airspeed Versus Frequency of Occurrence at 40- to 50-Percent Torque Split (11 Sample Points).

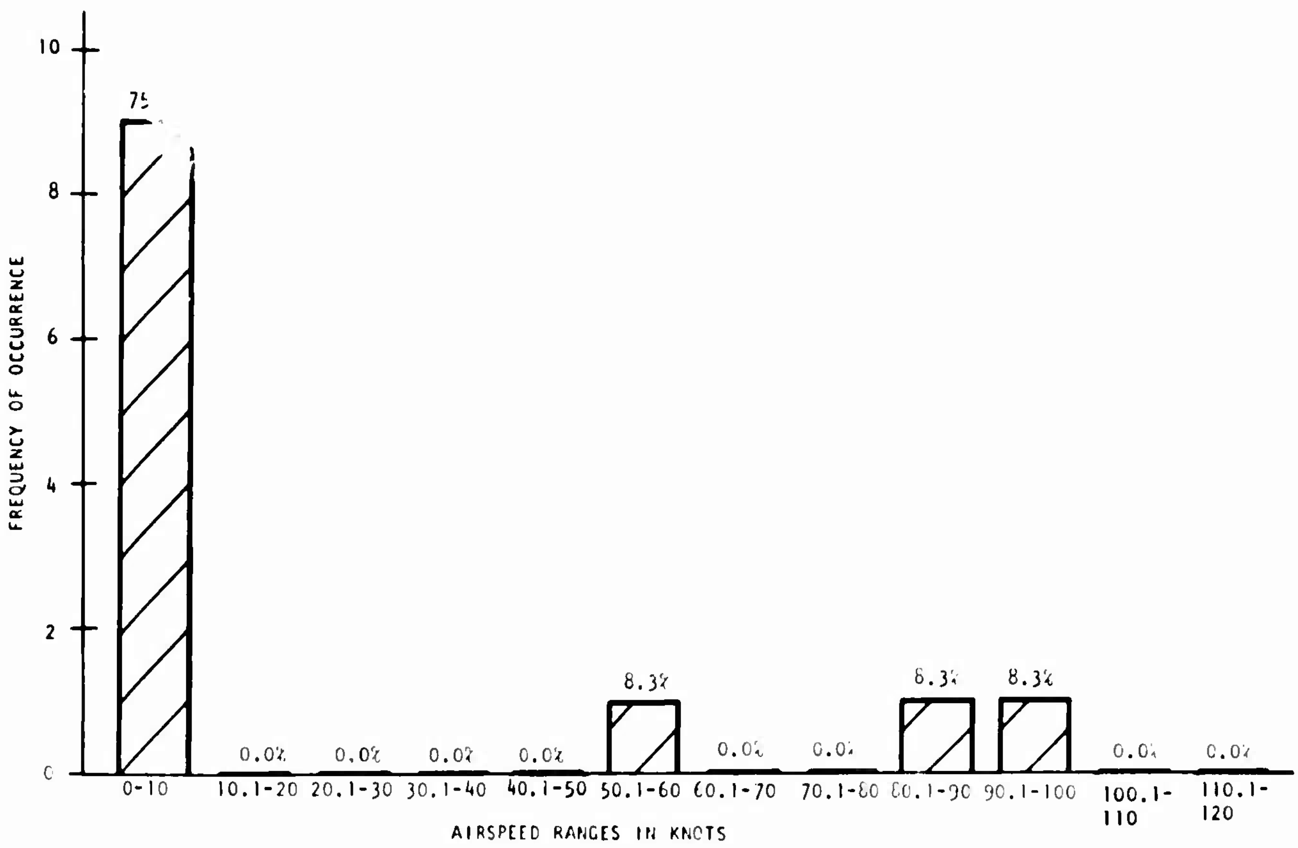

Figure 39. Airspeed Versus Frequency of Occurrence at 50- to 60-Percent Torque Split (12 Sample Points).

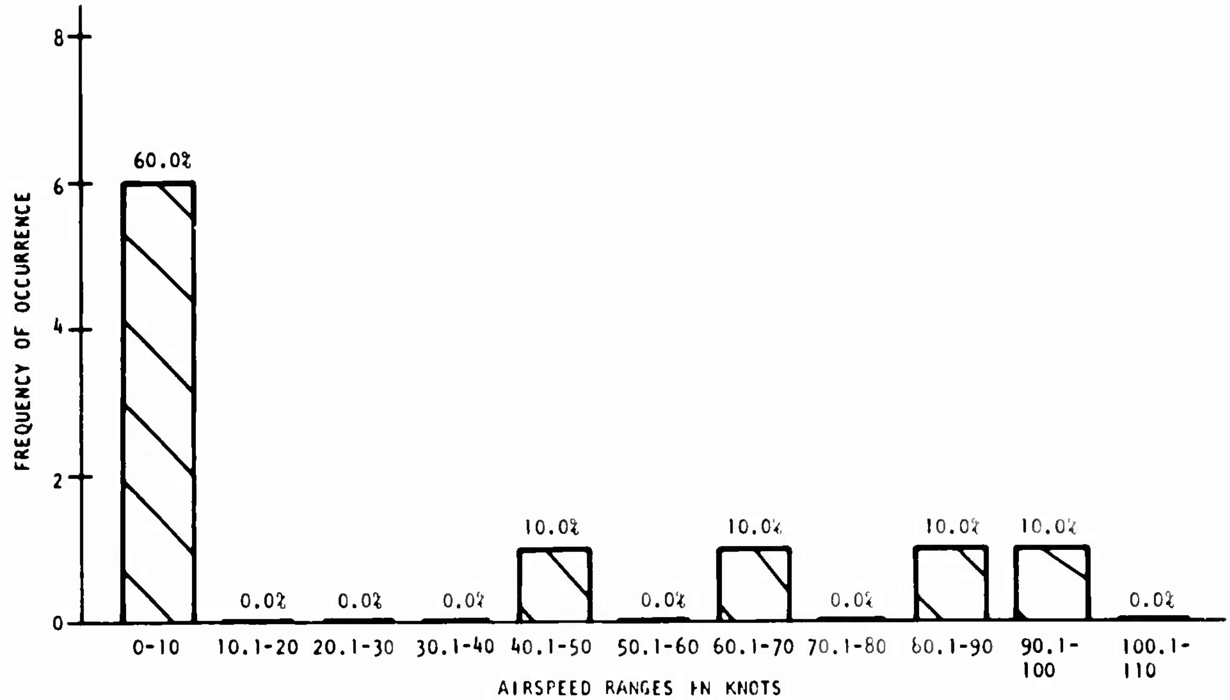

Figure 40. Airspeed Versus Frequency of Occurrence at 60- to 70-Percent Torque Split (10 Sample Points).

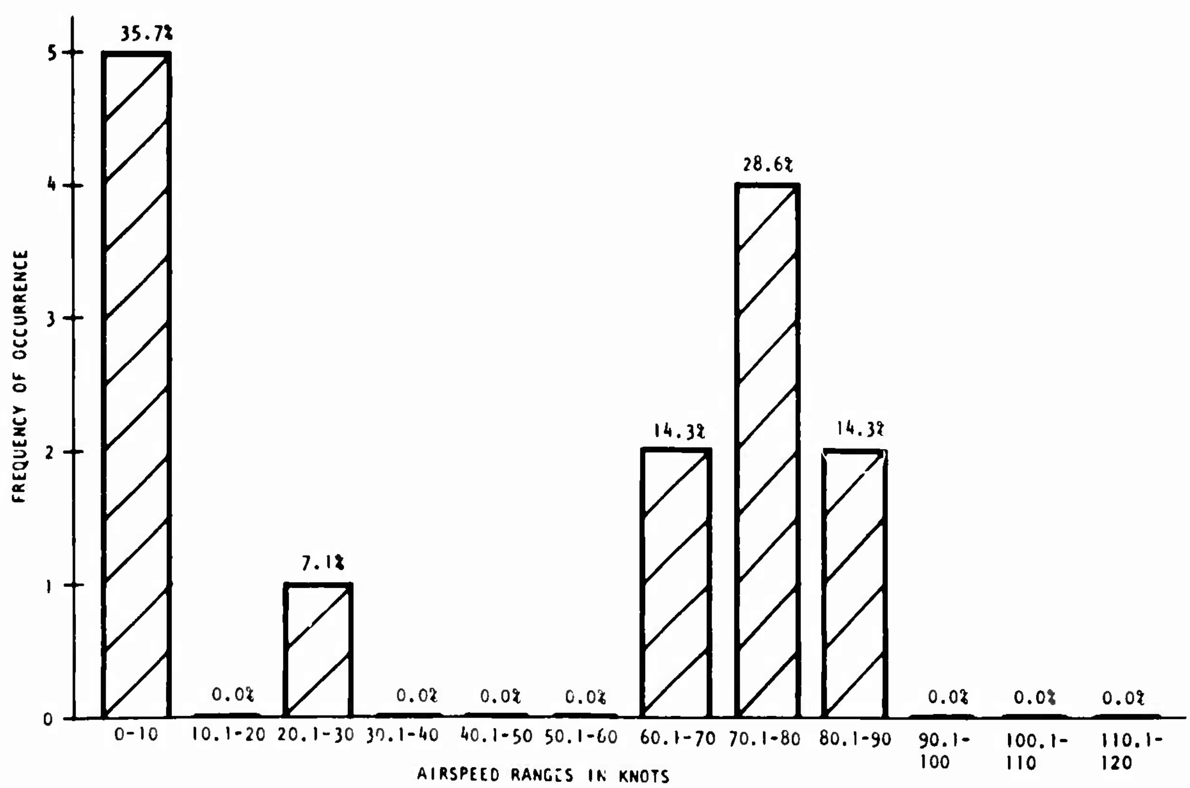

Figure 41. Airspeed Versus Frequency of Occurrence at 70- to 100-Percent Torque Split (14 Sample Points).

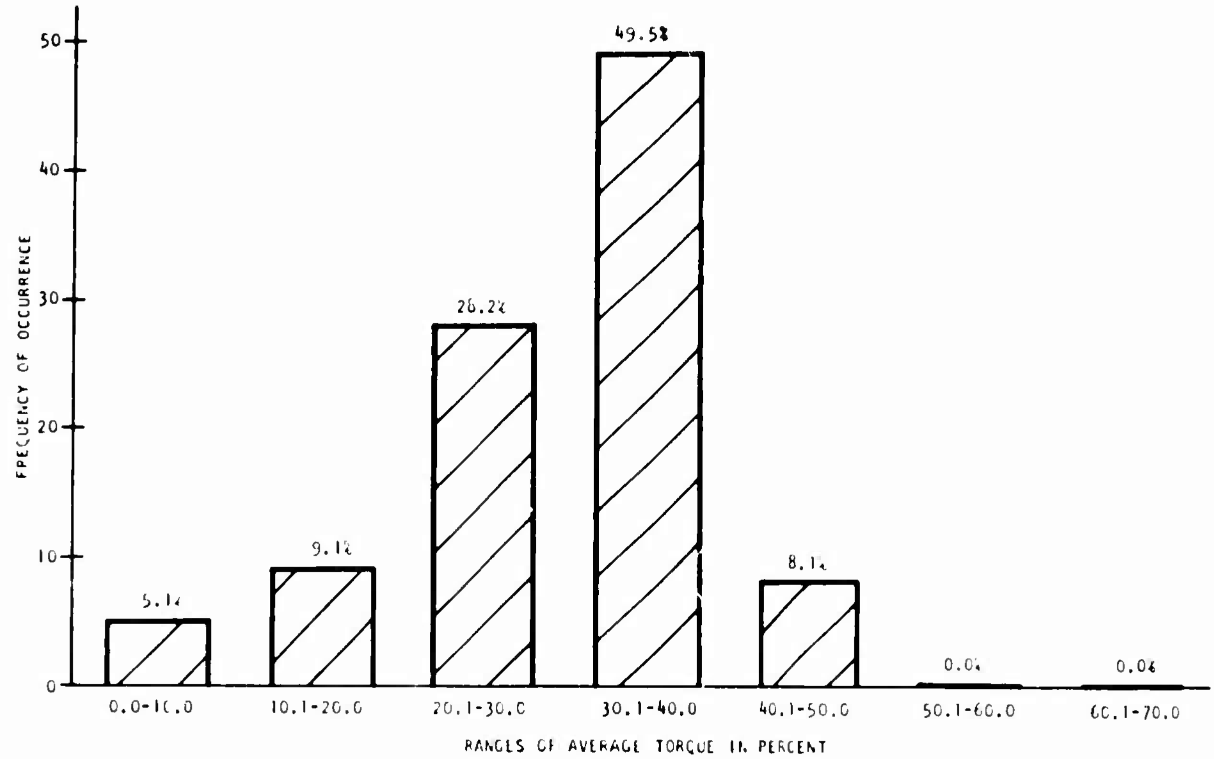

Figure 42. Average Torques per Engine Versus Frequency of Occurrence at 0- to 10-Percent Torque Split (99 Sample Points).

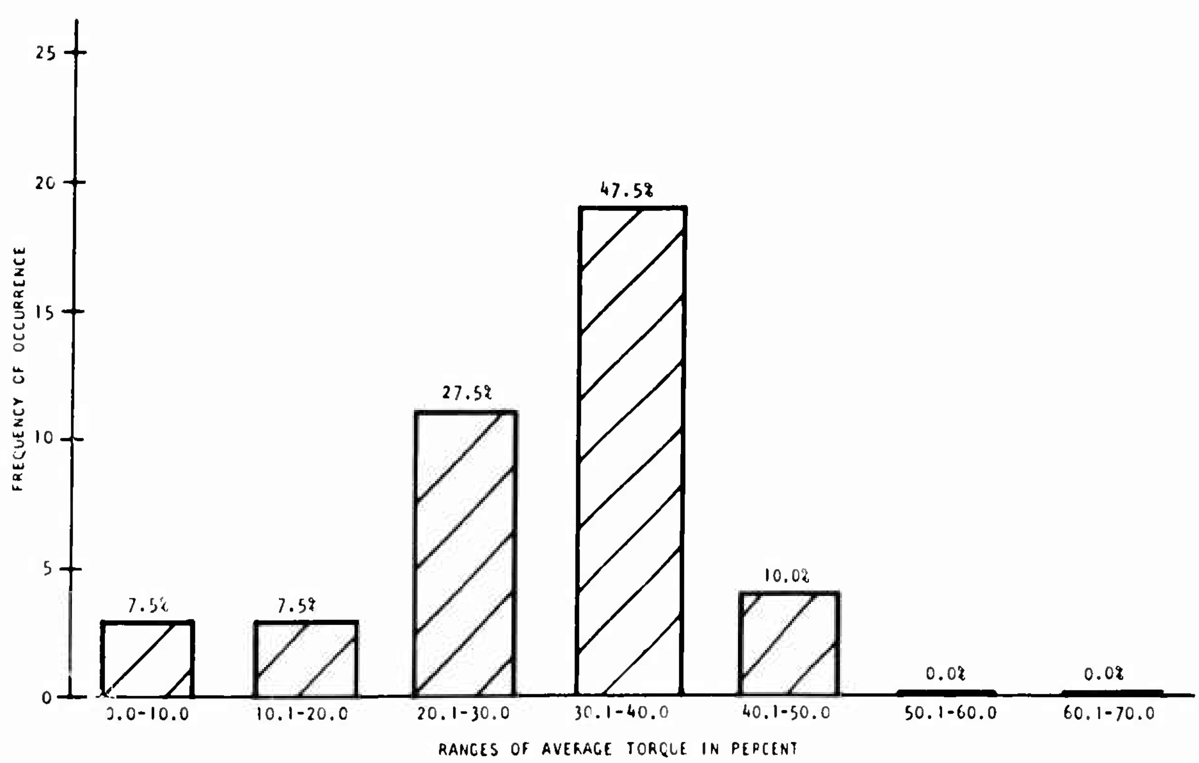

Figure 43. Average Torques per Engine Versus Frequency of Occurrence at 10- to 20-Percent Torque Split (40 Sample Points).

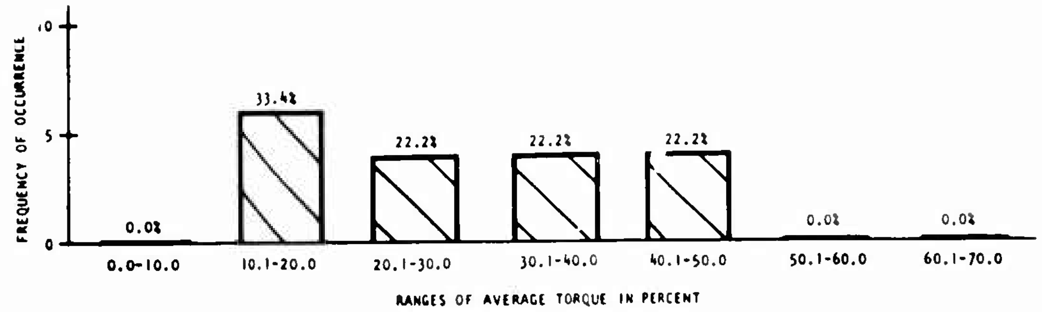

Figure 44. Average Torques per Engine Versus Frequency of Occurrence at 20- to 30-Percent Torque Split (18 Sample Points).

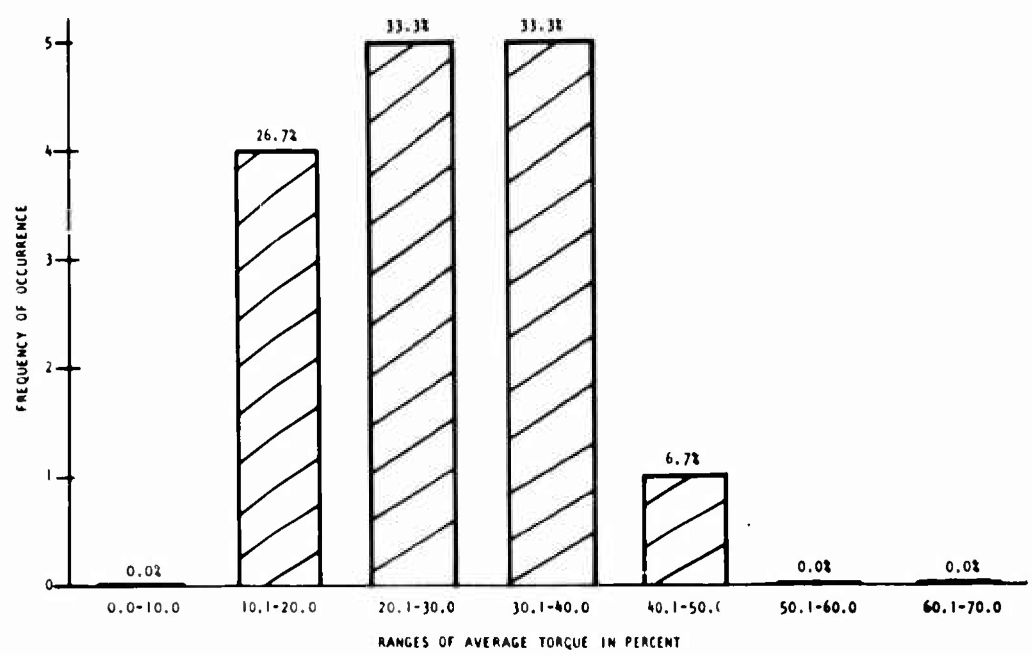

Figure 45. Average Torques per Engine Versus Frequency of Occurrence at 30- to 40-Percent Torque Split (15 Sample Points).

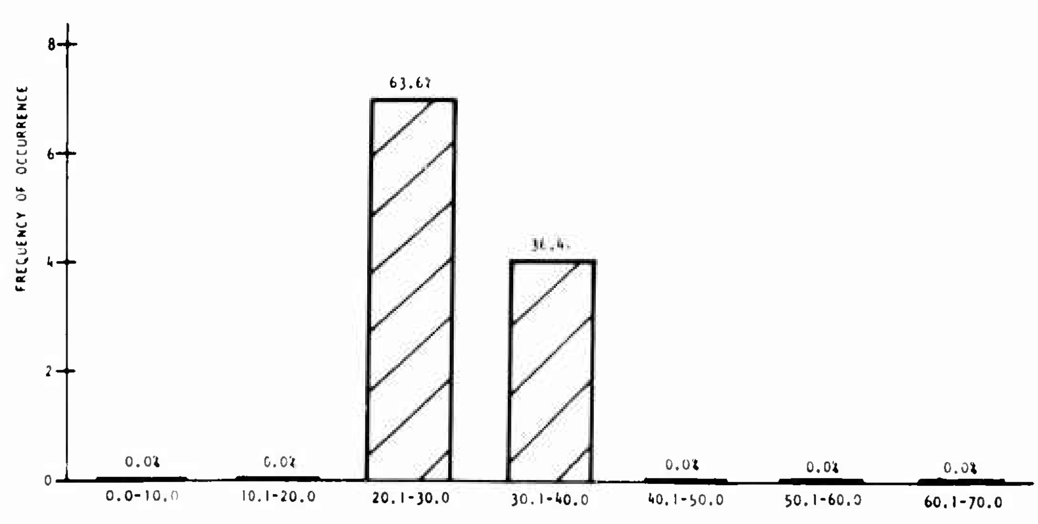

Figure 46. Average Torques per Engine Versus Frequency of Occurrence at 40- to 50-Percent Torque Split (11 Sample Points).

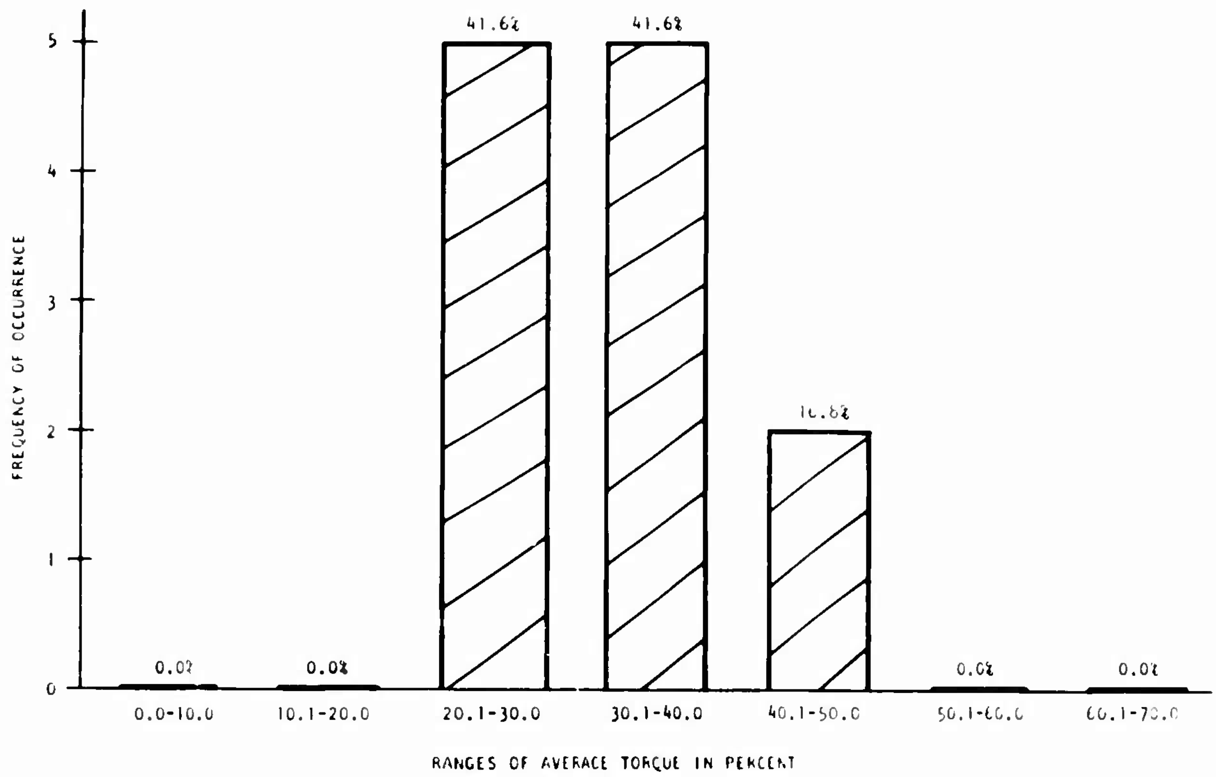

Figure 47. Average Torques per Engine Versus Frequency of Occurrence at 50- to 60-Percent Torque Split (12 Sample Points).

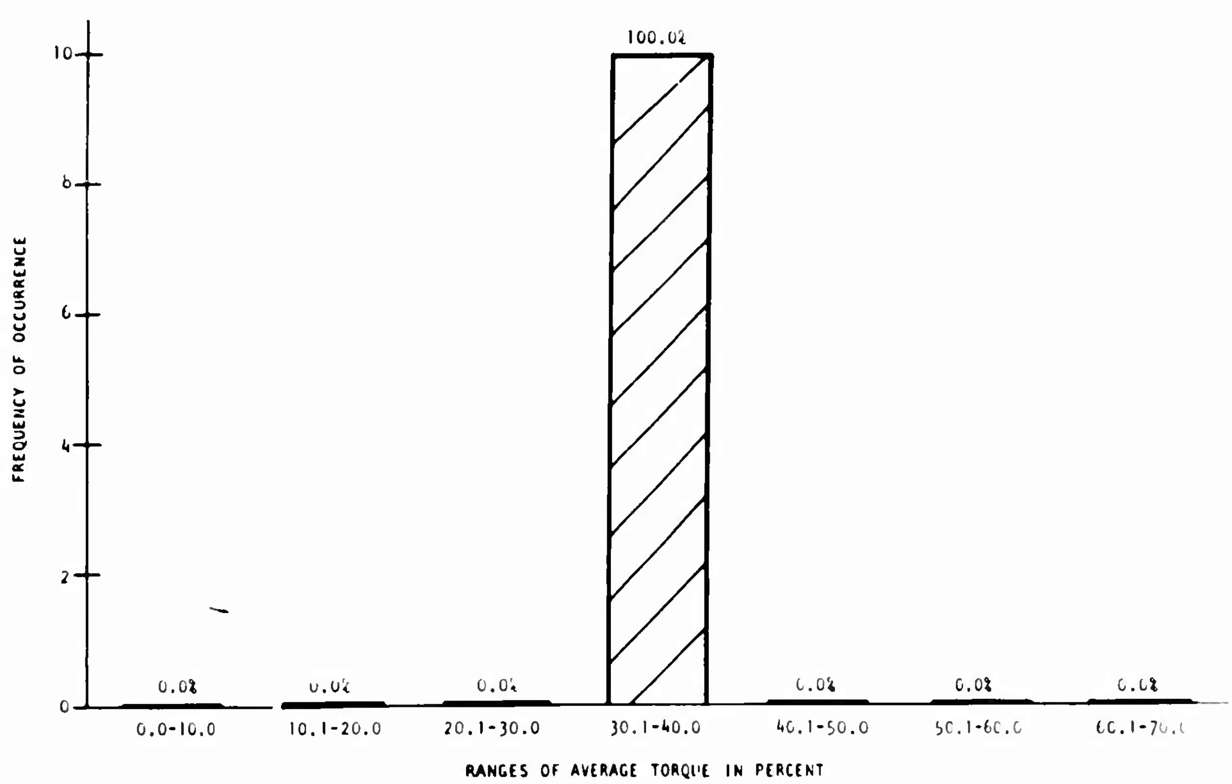

Figure 48. Average Torques per Engine Versus Frequency of Occurrence at 60- to 70-Percent Torque Split (10 Sample Points).

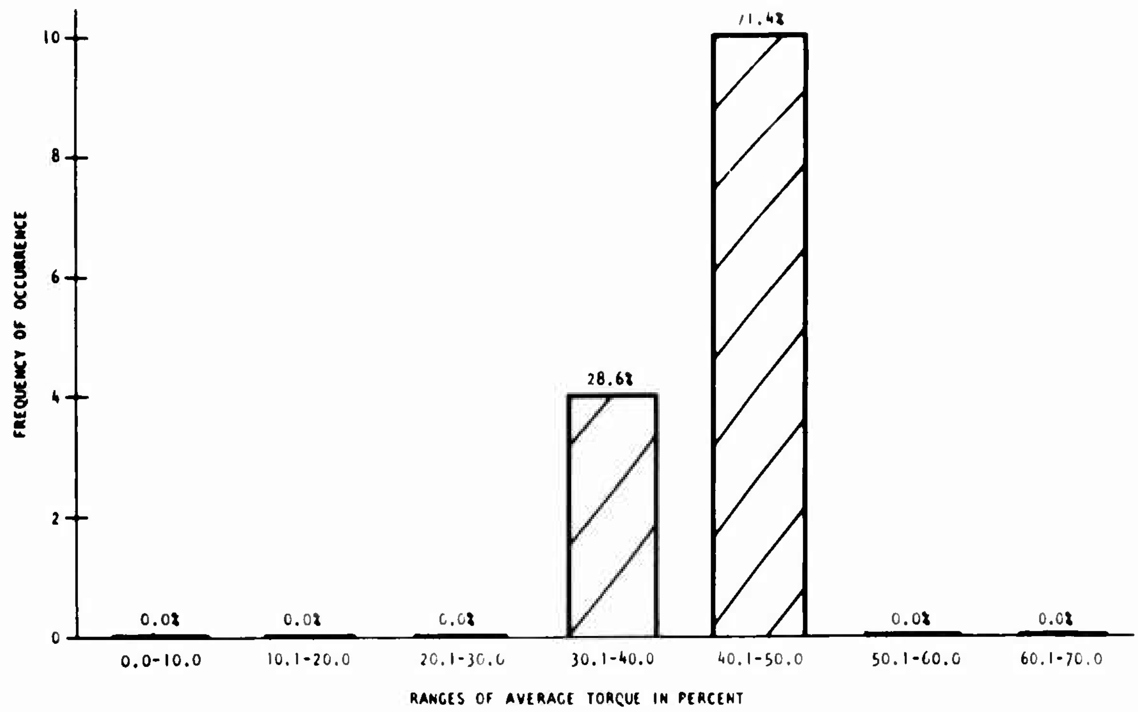

Figure 49. Average Torques per Engine Versus Frequency of Occurrence at 70- to 100-Percent Torque Split (14 Sample Points).

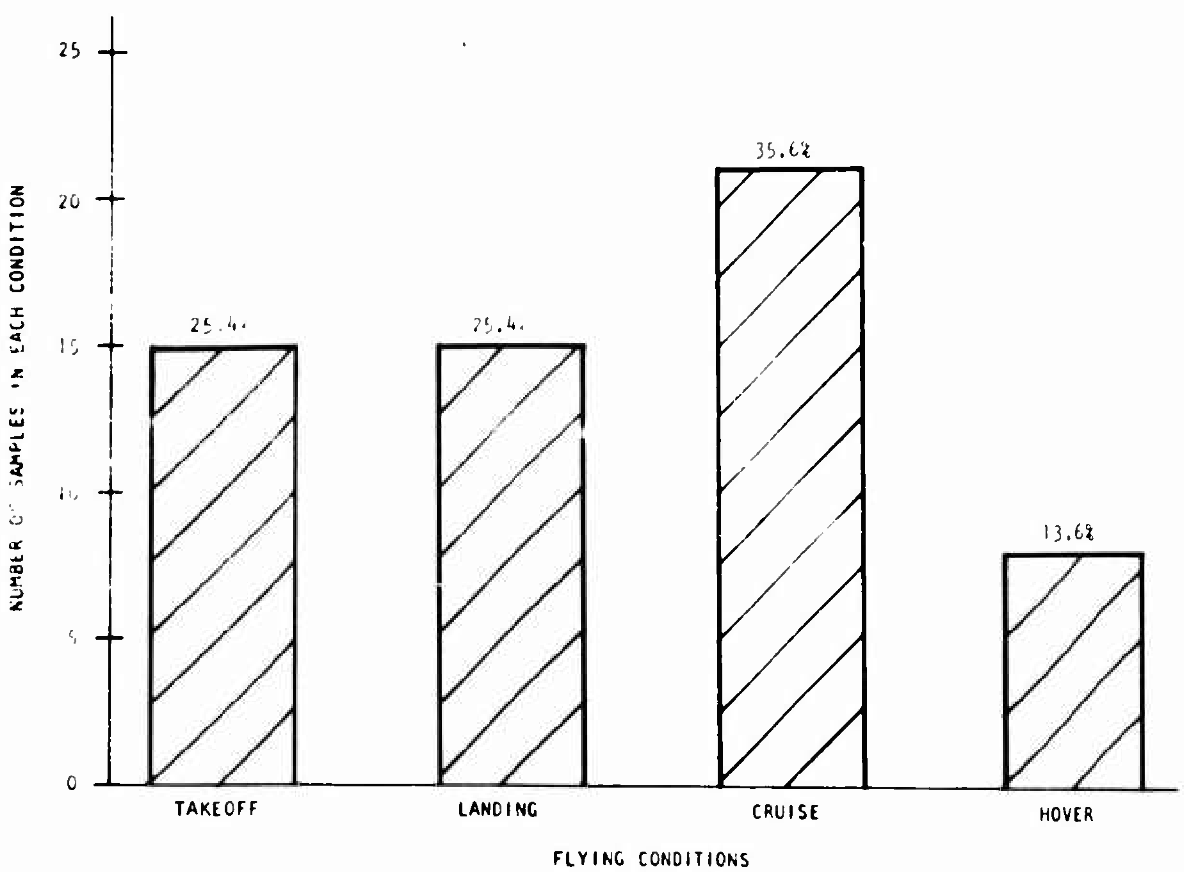

Figure 50. Percentage of Time in Various Flight Modes During Torque Splits.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) US Army Aviation Materiel Laboratories Fort Eustis, Virginia	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

CH-54A Skycrane Engine Load Sharing

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
Engineering Laboratory Report

5 AUTHOR(S) (Last name, first name, initial)

Chestnutt, David
Bartek, L. R.

6 REPORT DATE May 1966	7a TOTAL NO OF PAGES 55	7b NO OF REFS

8a CONTRACT OR GRANT NO. b. PROJECT NO 1M121401D14415, House Task EL 65-29 c d	9a ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 66-47 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY US Army Aviation Materiel Laboratories Fort Eustis, Virginia

13 ABSTRACT

The Army is considering the use of multiengine heavy-lift helicopters in its future aviation program. The engine-load-sharing characteristics of the CH-54A Skycrane helicopter were investigated to determine if unequal load sharing would be a significant problem. Torque-split samples were selected from 67 hours of flight-load data. The parameters measured and recorded on oscillograph records were airspeed, altitude, engine gas producer rpm, engine torque, main rotor rpm, vertical acceleration at aircraft center of gravity, and outside air temperature. Barometric pressure and gross weight at takeoff and landing were measured and recorded as supplemental data. The data gathered were presented as a series of frequency-of-occurrence graphs indicating variation in torque splits with the other measured parameters. The analysis of the data indicates that the engine load splitting is significant at takeoff and landing and should be investigated further.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Heavy-Lift Helicopters						
Helicopter Engine Load Sharing						
Operational Helicopter Data						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification

2861-66